

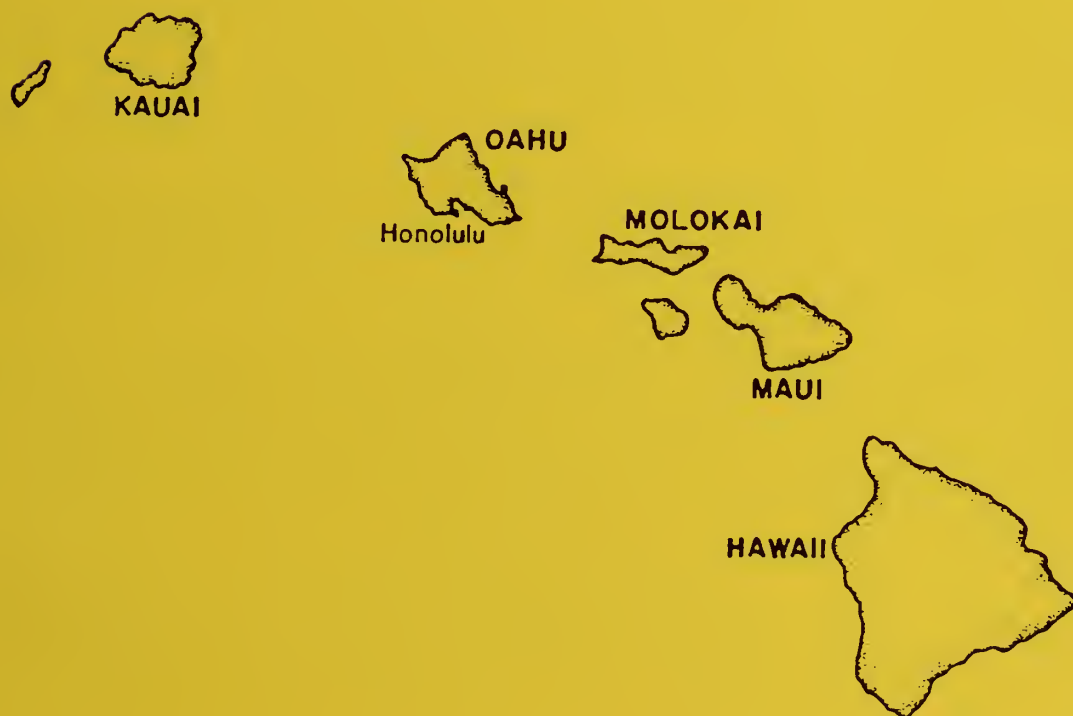
Biological Services Program

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April 1978

Stream Channel Modification in Hawaii.

Part A: Statewide Inventory of Streams; Habitat Factors and Associated Biota



Fish and Wildlife Service

U.S. Department of the Interior

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STREAM CHANNEL MODIFICATION IN HAWAII
PART A: STATEWIDE INVENTORY OF STREAMS,
HABITAT FACTORS AND ASSOCIATED BIOTA

by

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PREFACE

This is the first of a four-part series on Stream Channel Modification (Channelization) in Hawaii and Its Effects on Native Fauna. Part A (and FWS/OBS-78/17, 18, and 19, later) was prepared for the National Stream Alteration Team to provide the much-needed baselines for evaluating future stream alteration proposals as well as ecological information applicable to the protection and preservation of native Hawaiian stream fauna. This report is an inventory of channel modifications on perennial streams and general biota survey. Stream alteration data include date of origin, type and distance from the stream mouth. Ecosystem data include discharges, stream profiles, and qualitative biota survey. Streams are classified according to ecological quality using the proposed status-use categories of the Hawaii State Department of Health. Inventory started in August 1975 and finished in September 1976. Refinement of inventory and report continued until February 1978.

Any suggestions or questions regarding Channel Modification in Hawaii should be directed to:

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EXECUTIVE SUMMARY

There are at least 366 perennial streams in the five largest islands of Hawaii. Fifteen percent of these streams have been altered. Six types of channel alteration have been identified: lined channel, channel realignment and riparian clearance, elevated culvert, revetment, filled-in channel, and extended culvert. A total length of 151 km of these modifications has been identified. The comparative "abundances" of these are: lined channel, 40%; realigned/cleared, 28%; revetment, 24%; filled-in channel, 5%; elevated culvert, 3%; and extended culvert, <1%. Eighty-nine percent of the total length of lined channel is located on Oahu.

On the basis of other human disturbances, only 14% of Hawaiian streams may be physically pristine, and none of these physically pristine streams is on Oahu, the most populous island in the State. There are apparently no longer any biologically pristine streams, since at least one exotic species was found in all streams sampled. Only 27% are of high ecological quality (pristine-preservation use), and none of these high ecological quality streams is on Oahu. Water is exported from 53% of all perennial Hawaiian streams.

Twenty-five species of fish and decapod crustaceans were collected statewide. Only eight of the species are native to the State. Both in numbers and biomass, native species are dominant in most unaltered streams, while exotic species are dominant in altered streams.

This report was submitted in fulfillment of Contract No. 14-16-0008-1199 by the Hawaii Cooperative Fishery Research Unit under the sponsorship of the Office of Biological Services, U.S. Fish and Wildlife Service. Work was completed February 28, 1978.

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LIST OF ABBREVIATIONS AND SYMBOLS IN TEXT

ABBREVIATIONS

cm	centimeters
cm ³ /s	cubic centimeters per second
km	kilometers
km ²	square kilometers
m	meters
m ³ /s	cubic meters per second
μmhos	micromhos
USGS	United States Geological Survey

SYMBOLS

A	channel altered
C	continuous stream
Ca	Calcium
CaCO ₃	Calcium carbonate
I	interrupted
K	Potassium
Mg	Magnesium
N	channel not altered
Na	Sodium
●	abundant
○	common
○	rare-occasional
	lined channel
	realigned/cleared
	elevated culvert
	revetment
	blocked or filled-in
	extended culvert

°C	degrees, Celsius
NW	northwest
SE	southeast
°N	degrees, North latitude
°W	degrees, West longitude

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INTRODUCTION

Numerous perennial streams occur on the five largest islands in the State, representing the principal environments of native freshwater animals. Most streams are small by continental standards, their drainage basins and flows being functions of the size, elevation, and geological age of the island, and of the nature of local rainfall. Characteristic flows are seasonally variable, with discharge fluctuations up to a thousandfold recorded from summer lows to winter freshets. Cultural modifications of natural stream ecosystems have been most severe at lower elevations. Channel modification is one of the three principal cultural changes, the others being dewatering (mainly for irrigation) and the introduction of exotic species.

Although perennial streams constitute Hawaii's principal type of inland aquatic ecosystem, no comprehensive list of streams nor descriptive inventory of channelization exists. The effects of channel modifications have been observed only superficially. The purposes of this study are: (1) to produce an inventory of all perennial streams of Hawaii that emphasizes significant channel modifications statewide by design type, size, age and geographic location; (2) to assess relevant environmental parameters that may influence the occurrence and abundance of native stream animals; (3) to make an inventory of stream macrofauna, particularly that associated with modified channels; and (4) to discern one or more species whose presence indicates reasonably pristine conditions.

BACKGROUND

STREAM FAUNA

Hawaii's native stream fauna is unique in several ways. It is particularly adapted to the rocky, precipitous, freshet-flow nature of Hawaiian streams. The number of species within a given taxon are few but most of them are endemic. Excluding insects, all larger native stream species are diadromous (having marine larval development) as a consequence of invasion from the oceanic ecosystem and incomplete adaptation to freshwater life. These diadromous animals include 6 fish species (5 of them endemic), 2 mollusks (1 endemic), 2 shrimps (both endemic), and a polychaete worm. Among the fishes, the goby, Lentipes concolor, is on the American Fisheries Society list of rare and endangered species, and three other species are considered as threatened (Miller 1972). Perhaps it is no coincidence that Lentipes, originally described in part from Oahu where today channel modification is most extensive, is now unknown on that island. Furthermore, unpublished surveys indicated that two other Hawaiian stream endemics, a freshwater limpet (Neritina granosa) and a prawn (Macrobrachium grandimanus), are becoming depleted.

Some native stream species provide an unmanaged fishery; goby (Awaous stamineus), freshwater limpet (N. granosa), atyid shrimp (Atya bisulcata), and prawn (M. grandimanus), are important locally as traditional food items and are marketed commercially. The impact of channelization on fauna of oceanic islands such as Hawaii can be especially severe inasmuch as the most extensive modifications are developed mainly on the lower reaches of streams. These reaches, in addition to being habitats of some species, are the essential migratory pathways for both seaward-moving larvae and returning juveniles of the native species inhabiting the upper reaches (see also Table 1).

Superimposed on the native animal communities are a large number of introduced aquatic species, most of which are highly successful competitors or predators. Within a group of nearly 50 foreign non-marine animals (decapod crustaceans, mollusks, amphibians, and mostly fishes) known to have been released in Hawaii, 36 species have become established. Among the 36 established exotics, 27 species are found in streams (Kanayama 1968). In addition, many species of foreign aquatic insects and lower invertebrates also occur in streams. Considering overall diversity of stream fauna and relative unobtrusiveness of many species, faunal inventory in this project

Table 1. Characteristic Fish and Decapod Crustacean Inhabitants
of Hawaiian Streams^a

Scientific name	Common name	Local name	Status ^b
Crustaceans			
<u>Atya bisulcata</u>	Atyid shrimp	Opae kalaole	Endemic
<u>Macrobrachium grandimanus</u>	Hawaiian prawn	Opae oehaa	Endemic
<u>Macrobrachium lar</u>	Tahitian prawn	--	Introduced
<u>Procambarus clarkii</u>	Crayfish	--	Introduced
Fishes			
<u>Awaous genivittatus</u>	Goby	O'opu naniha	Indigenous
<u>Awaous stamineus</u>	Goby	O'opu nakea	Endemic
<u>Cichlasoma</u> sp.	Cichlid	--	Introduced
<u>Clarias fuscus</u>	Chinese catfish	--	Introduced
<u>Cyprinus carpio</u>	Carp	Koi	Introduced
<u>Eleotris sandwicensis</u>	Eleotrid	O'opu okuhe	Endemic
<u>Gambusia affinis</u>	Mosquitofish	Medaka	Introduced
<u>Kuhlia sandvicensis</u>	Kuhliid	Aholehole	Endemic
<u>Lentipes concolor</u>	Goby	O'opu alamoo	Endemic
<u>Lepomis macrochirus</u>	Bluegill	--	Introduced
<u>Micropterus dolomieu</u>	Smallmouth bass	--	Introduced
<u>Misgurnus anguillicaudatus</u>	Oriental weatherfish Loach	Dojo	Introduced
<u>Ophecephalus striatus</u>	Snakehead	--	Introduced

Continued

Table 1 (Concluded)

Scientific Name	Common Name	Local Name	Status
<u>Poecilia latipinna</u>	Sailfin molly	--	Introduced
<u>Poecilia mexicana</u>	Shortfin molly	--	Introduced
<u>Poecilia reticulata</u>	Guppy	--	Introduced
<u>Poecilia vittata</u>	Topminnow	--	Introduced
<u>Sicydium stimpsoni</u>	Goby	O'opu nopili	Endemic
<u>Tilapia (= Sarotherodon) mossambica</u> ^c	Tilapia, Mossambique mouthbrooder	--	Introduced
<u>Xiphophorus helleri</u>	Green swordtail	--	Introduced
<u>Xiphophorus maculatus</u>	Southern platyfish	--	Introduced

^aFor a complete list of aquatic macrofauna in large Hawaiian streams, see Timbol, 1977.

^bThe terms "endemic" and "indigenous" are used to designate "occurring naturally in Hawaii only" and "occurring naturally in Hawaii and also elsewhere", respectively. According to Maciolek (MS) all five gobies (o'opu) and the Hawaiian prawn are "obligately diadromous, meaning they must travel twice between sea and stream habitats as a necessary part of their life cycles." The atyid shrimp is also diadromous but possibly can complete its life cycle entirely in the stream.

^cOther tilapia species, T. macrochir, T. melanopleura, and T. zilli, are known to be established in Hawaii's streams.

was limited to the most representative taxa of large stream animals that were easiest to collect, identify, and observe: fishes and decapod crustaceans.

PHYSIOGRAPHY AND THE STREAM ENVIRONMENT

The inhabited (high) islands of the Hawaiian Archipelago are arranged in a NW → SE line 1,110 km long between latitudes 22° N and 19°N. This portion of the State is entirely within the Torrid Zone, but because of cooler winds flowing over it, it is considered as subtropical (Stearns 1946). The six major islands, from west to east, are: Kauai, Oahu, Molokai, Lanai, Maui, and Hawaii (Fig. 1). The islands are successively younger from Kauai to Hawaii (Zimmerman 1948).

According to Blumenstock and Price (1967), Hawaii has only two seasons, a winter season of seven months (October through April) and a summer season of only five months (May through September). Persistent rainfall is associated with tradewinds (orographic) and seasonal storms with frontal systems. Rainfall distribution is highly variable, from less than 30 cm/yr in leeward coastal areas to over 760 cm/yr along the windward slopes of high mountains or near the summits of lower mountains. The temperature regime is not as variable as the rainfall pattern, at least in the lowlands. Daytime temperatures range from 20 to 26° C and nighttime temperatures from 15 to 20° C.

To provide a background for understanding the nature of stream and related ecosystems in Hawaii, the description of a representative stream is helpful. Kahana, on the windward coast of Oahu, which has been studied previously (Kubota 1972, Timbol 1972), is presented here as an example. It is one of the few unaltered Oahu streams to have permanent and unpolluted flow from headwaters to the sea. The Kahana mainstream averages about 8 m wide and has a depth range between 1 and 4 m, while Kawa tributary averages 4 m wide with a depth range between 0.3 and 1.2 m. Stream flow at elevations between 10 and 180 m is turbulent. Above 180 m, the stream is reduced to a series of pools and steep rivulets which flow intermittently. Kahana mainstream has a long-term mean discharge of 0.49 m³/sec (Takasaki et al. 1969). Another 0.25 m³/sec is exported from the valley (USGS 1968). Short-term data for Kawa tributary show an annual mean discharge between 0.07 m³/sec (1914-1917) and 0.12 m³/sec (1960-62) (USGS 1962). Daytime surface water temperature for the stream system in the year 1970-1971 averaged 22° C (range 18 - 24° C). Conductivity was low with a mean value of 106 µmhos (range 80 - 146).

CHANNELIZATION

Continued channel modification in Hawaii is certain, as evidenced by current channelization proposals for Kahoma and Iao Streams on Maui and Makaha Stream on Oahu. Presently on Oahu, a dam is being constructed across Kamooalii tributary of Kaneohe Stream. Environmental commentary is difficult because of the lack of definitive information on the effects of

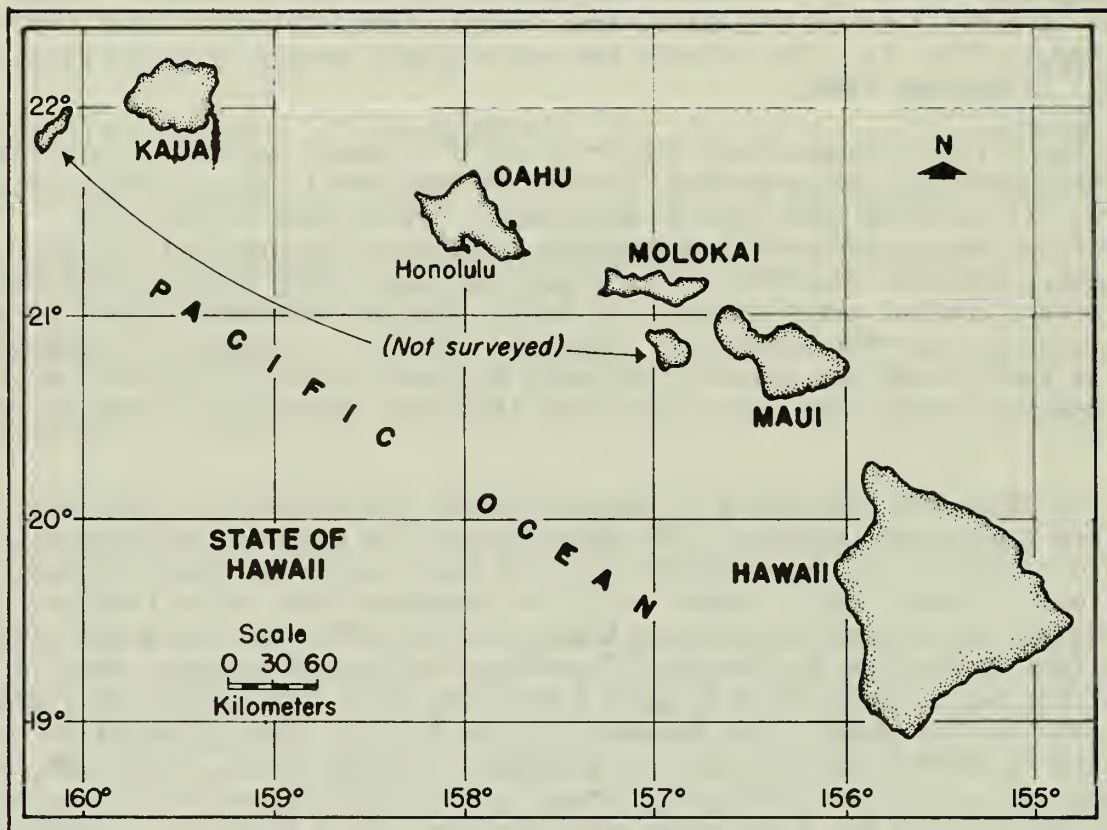


Figure 1. The State of Hawaii showing the five major islands surveyed for stream channel modification.

channelization either on total stream ecology or on individual native species. Past commentaries have been based on generalized information (mainland U.S. and limited ecological data on Hawaiian streams) and a few specific observations on local channelization effects. Concrete-lined flat-bottom channels, as shown in Fig. 2, obviously provide no habitat for native fishes and crustaceans, and expose water to excessive insolation. The effects of such lined channels on the quality and quantity of fauna upstream (i.e., effects on migration) or on the downstream environment (e.g., heating) are unknown. Such are examples of the principal informational needs today.

This report concerns that portion of the project involving a one-year (August 1975 - September 1976) statewide, exhaustive inventory of perennial streams with channel modifications, including a general survey of habitat factors and macrofauna. It includes the islands of Kauai, Oahu, Molokai, Maui, and Hawaii (Fig. 1). Niihau and Lanai, the remaining two inhabited islands in the State, were not surveyed. Niihau is small, relatively arid, and under private ownership that prohibits entry of non-residents. Lanai apparently has only one stream, and it is located in an area of difficult access. It is assumed that this lone stream is not channelized.



Figure 2. Lined channel of lower Palolo Stream, a tributary of Manoa Stream, Honolulu. Flat bed spreads low-flow water into a thin sheet that provides no shelter for native fishes or crustaceans and causes excessive solar heating.

METHODS

For project purposes, a stream is defined as surface water flowing in a discrete channel or channel system that discharges to the ocean at a single point. Thus, a given stream may have a single dominant channel or a complex of branching tributaries. Two classes of perennial streams are distinguished: Continuous streams flow naturally to the sea year-round under normal conditions; Interrupted streams have ecologically significant perennial water in their upper watercourses and intermittent flow in their channels at low elevations. Interrupted streams discharge into the sea occasionally during the wet seasons. These terms are applied both to mainstream and named tributaries.

STREAM SURVEY

A list of streams was prepared from USGS quadrangle maps of the various islands of the State. Channel modifications were identified from field surveys and from the 1975 Real Estate Atlas. The channel modifications and alterations considered in this report are defined in the legend for Appendix B. Total lengths of channelized streams were estimated by measurement of the watercourses drawn on the USGS quadrangle maps and field checked. Lengths of altered channel sections were determined by measurement from the Real Estate Atlas whenever possible. Dates of channel modifications were obtained from various governmental agencies. Maps of the drainages and channels of altered streams were prepared from USGS topographic maps for each island (scale = 1:62,500) and in some cases from topographic quadrangle sheets (scale = 1:24,000). Discharges are from USGS water-data reports. Water diversion information, which includes diversions by water tunnels, aqueducts, ditches, flumes, siphons, wells, pumps, and reservoirs, comes from USGS topographic quad sheets (1957, 1963). Roadways crossing stream channels, which include heavy-duty, medium-duty, light-duty, and unimproved dirt roads but not hiking trails, also come from these maps. Water quality standards are those proposed by the Hawaii Department of Health (Hawaii Department of Health 1977).

PHYSICOCHEMICAL

Water temperature and dissolved oxygen were determined with the use of a YSI Model 54 oxygen meter, conductivity with a YSI Model 33 S-C-T meter,

and pH with an AM Model 107 analytical pocket pH meter. Additional information came from USGS and Hawaii State Department of Health publications.

BIOLOGICAL

Stream macrofauna collections were made with battery- and generator-energized backpack electroshockers. Electrofishing was employed because it is the most effective and quickest method of sampling the principal stream animals: fishes and decapod crustaceans. The term "macrofauna" as used herein, is thus applied to include all species within those two major taxa. In most cases, collections from a given stream were made at three locations: in the freshwater portion nearest to the mouth, within the altered channel, and upstream from channel modifications. All specimens collected from a 20 m X 1 m sampling zone were counted, measured, and weighed for abundance and distribution data. Generally, electroshocking was continued beyond the 20-m zone to determine if additional species were present. Species found by sampling or sighting beyond the 20-m zone are included in the inventory of specimens. Because collections were made in small sections of channel, usually in lower stream reaches, faunal inventories here do not represent species complement or distribution of fishes and crustaceans in the entirety of any given stream (see comments under FAUNA OF OAHU STREAMS).

The inherent limitations of the electroshocking method should be considered when looking at the abundance and distribution results. The shocker effectiveness may be limited to shallow waters, and the stunned organisms may collect under any cover available (Riggs 1953). Furthermore, the efficiency of electrofishing in streams is directly affected by the behavior, habitats, and morphology of the species (Larimore 1961). However, since data are given here in relative terms of rare-occasional, common, and abundant, it can be safely assumed that the measured abundances and distributions of the macrofauna permit realistic comparisons. For project purposes, rare-occasional (0) indicates that either only one specimen was collected per sampling or it was sighted but not captured. Common (●) indicates that the species is obtained every time a collection is made but not in abundance (usually between 2 and 5 specimens). Abundant (●) means many specimens are obtained in a collection (usually 6 to 100 or more).

References used in the identification of specimens were:

Fishes: Gosline and Brock 1960
Jordan and Evermann 1903

Crabs: Edmondson 1946
Rathbun 1906

Prawns and shrimps: Edmondson 1929
Holthuis 1950, 1951-1952
Rathbun 1906

Unfamiliar fish specimens were sent to the Smithsonian Institution and identified by Dr. William Fink.

HAWAIIAN STREAMS AND TYPES OF MODIFICATIONS

All perennial streams on the five islands surveyed are listed in Appendix A. In addition, Appendix A includes information on stream mouth locations by grid coordinates, topographic map name wherein located, water diversions, number of roadways crossing stream channels, and ecological quality status for each stream. Six types of channel modifications are distinguished (see also symbols, Fig. 11):

1. Lined channel. An artificial channel having both natural banks and stream bed replaced, usually with concrete. It may be flat bottom or v-shaped. Representative examples are in Palolo tributary of Manoa Stream and Ahuimanu tributary of Kahaluu Stream (Figs. 3 and 4).
2. Vegetation removed-channel realigned. Represented by Kapalama Stream (Fig. 5).
3. Elevated culvert. These are conduit structures that are comparatively short (typically <60 m), usually found under highways. Culverts placed in this category include only those where the culvert level is well above the water level immediately downstream, i.e., the culvert creates an artificial waterfall. An example of an elevated culvert is in Aolani tributary of Kaneohe Stream (Fig. 6). The numerous, short culverts at stream channel level were not inventoried.
4. Revetment. Where one or both banks of the stream are reinforced but the channel bed is not, as in Kalihi Stream (Fig. 7).
5. Blocked or filled-in channel. Where part of the original channel is blocked as in Pauoa tributary of Nuuanu Stream (Fig. 8).
6. Extended culvert. This is a longer version of modification type 3, usually found in residential areas as in Kawa Stream (Fig. 9).

Older examples of stream channel modification are the result of bridge building. The oldest forms of channel modification are clearing-realignment and revetments to reinforce stream banks. Most of these types of modifications on Oahu Island were done in the 1930 - 1950 period. The most significant form of modification ecologically and numerically is the lined



Figure 3. This flat-bottom lined channel (modification type 1) in Palolo tributary of Manoa Stream, Honolulu, is typical of lined channels found in streams on Oahu.



Figure 4. This lined channel in Ahuimanu tributary of Kahaluu Stream on windward Oahu, is representative of v-shaped construction with reduced flat-bottom area (modification type 1).



Figure 5. Kapalama Stream, between Dillingham Boulevard and North King Street in Honolulu, is an example of a realigned stream which has also been cleared of riparian vegetation (modification type 2).



Figure 6. Road and highway crossings often involve elevated culverts (modification type 3). This elevated culvert arrangement was constructed where Kahekili Highway crosses Aolani tributary of Kaneohe Stream, windward Oahu.



Figure 7. Revetments in Kalihi Stream, Honolulu (modification type 4). Stream bed is natural material; revetted banks consist of mortared rock and concrete sections.



Figure 8. A filled-in portion of Pauoa tributary of Nuuanu Stream, Honolulu (modification type 5). View is "downstream" from former bridge crossing at Iliahi Lane. Foreground rock wall is part of original bridge; former channel extended from fence on left to right edge of photograph.



Figure 9. Upstream end of an extended culvert on Kawa Stream at Kaneohe (modification type 6). This structure is located in the Parkway subdivision.

channel, the earliest of which was built in 1938 at Kapalama Stream. Lined channels represent a majority of recently built flood-control structures.

For each stream surveyed with an altered channel, Appendix B contains a map showing watershed limits, mainstream channel and principal tributaries, the longitudinal gradient of mainstream, and the types and approximate locations of channel modifications. Locations of biological samples and relative abundances of species are also shown.

Pressures of an increasing population have a direct, mostly adverse effect on streams, especially small streams. An ever increasing amount of stream water is diverted both for agricultural purposes and domestic use to support the population. Also, new lands are opened for agricultural and housing purposes, resulting in more roads crossing over streams, less tree and grass cover, greater sediment loads, and stream channel alterations. The removal of natural vegetation inevitably alters the pattern of stream discharge (Hynes 1970). This report explores the extent to which Hawaiian streams have been degraded. For purposes of this report, a high quality stream is a completely natural stream that has not been changed detectably by human intervention, physically or biologically (Maciolek MS). A physically pristine stream is one where the stream channel has not been altered, its water is not diverted, and no roads (except foot trails) cross over it. A biologically pristine stream is one where only native species live.

STREAM AND FAUNA INVENTORY: OAHU ISLAND

STREAMS AND CHANNEL MODIFICATIONS

Oahu is the third largest island, measuring 71 by 48 km at its extreme dimensions and having an area of 1,564 km² (Foote et al. 1972). It emerged from the ocean during the Tertiary and possibly early Pleistocene (Stearns and Vaksik 1935). Two mountain ranges dominate the island's topography; Waianae rises to 1,227 m while Koolau reaches 960 m. Due to mountain configurations, rainfall gradients are steep, ca. 64 cm/km on the average. Rain varies from 50 to 635 cm/year on Oahu. Mean air temperature in Honolulu is 24° C with an absolute range of 11 - 32° C (Blumenstock and Price 1967).

Fifty-four perennial streams have been recognized on Oahu and are listed in Appendix A. Fifty-three percent of these are continuous and 47% are interrupted. Of the 54 streams, 31 (57%) are channelized. The locations of the altered (channelized) streams are shown in Fig. 10 and their features summarized in Table 2.

Among channelized streams, Waikele (Fig. 11) on the leeward side of Oahu, is the largest on the basis of stream length and watershed area. Keeaahala (Fig. 12), on the windward side, is the smallest. Waiawa exhibited the highest discharge for a single day (663 m³/s on January 5, 1958 per USGS 1975), and Waikele showed the highest long-term average discharge (1.1 m³/s, 21-year average; USGS 1975). Watershed limits, stream channels, longitudinal gradient of mainstream, and approximate locations of the channelized portions in each stream are shown in Appendix B.

A total of 134 km of modified channels occurs among the 31 altered streams. The relative "abundance" of each type of channel modification is indicated by its combined length in all 31 altered streams. Expressed as a percentage of the 134 km total altered channel length for the island:

- Lined channel - 43%;
- Cleared and realigned - 27%;
- Revetment - 23%;
- Blocked - 6%;
- Elevated culvert - <1%
- Extended culvert - <1%.

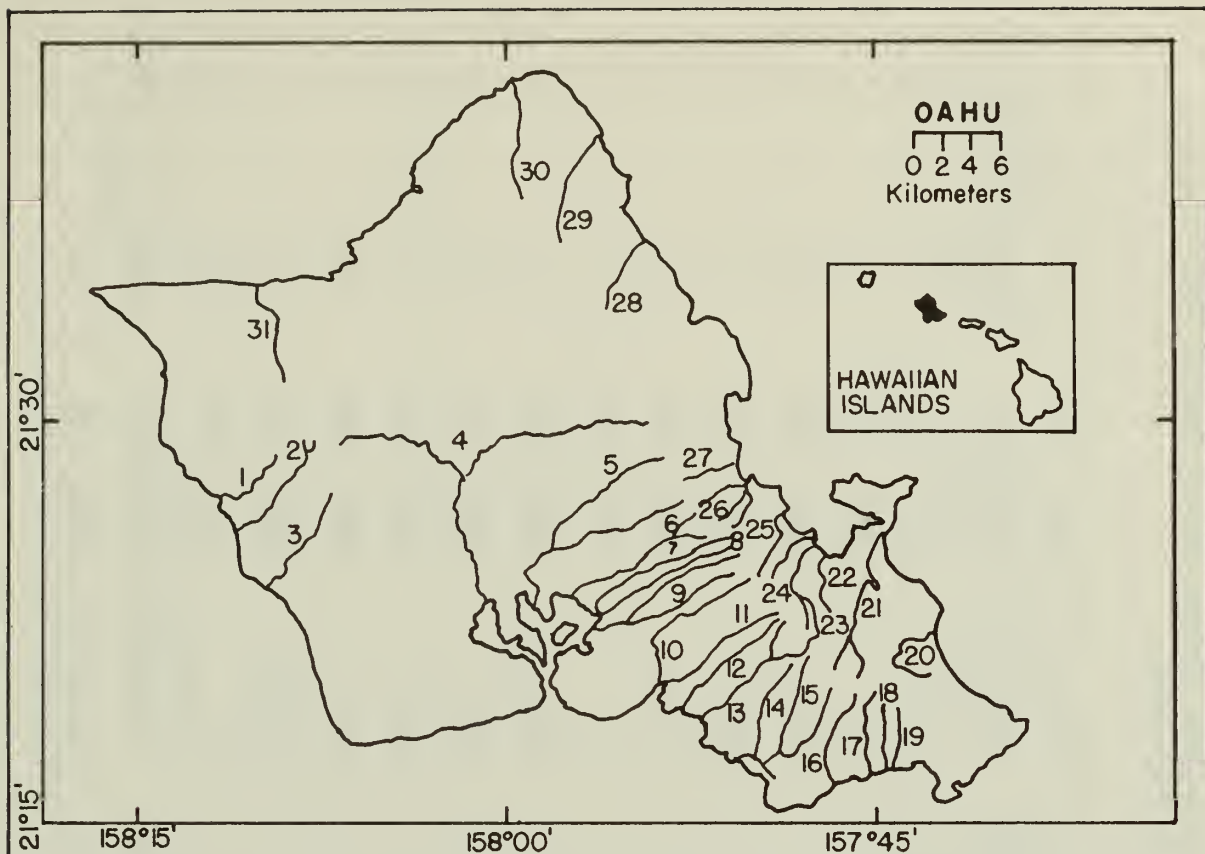


Figure 10. Location map for 31 Oahu streams having modified channels. Percentage of streams altered = $31/54 = 57\%$.

Legend:

- | | |
|-----------------------|------------------------|
| 1. Kaupuni Stream | 17. Wailupe Stream |
| 2. Mailiili Stream | 18. Pia Stream |
| 3. Ulehawa Stream | 19. Kuliouou Stream |
| 4. Waikele Stream | 20. Waimanalo Stream |
| 5. Waiawa Stream | 21. Maunawili Stream |
| 6. Waimalu Stream | 22. Kawa Stream |
| 7. Kalauao Stream | 23. Kaneohe Stream |
| 8. Aiea Stream | 24. Kaaahala Stream |
| 9. Halawa Stream | 25. Heeia Stream |
| 10. Moanalua Stream | 26. Kahaluu Stream |
| 11. Kalihi Stream | 27. Kaalaea Stream |
| 12. Kapalama Stream | 28. Kaipapau Stream |
| 13. Nuuanu Stream | 29. Malaekahana Stream |
| 14. Makiki Stream | 30. Oio Stream |
| 15. Manoa Stream | 31. Makaleha Stream |
| 16. Waialaenui Stream | |

Table 2. Some Physical Characteristics of the 31 Oahu Streams Having Channel Modifications.
See Fig. 3 for Locations.

Stream - Class ^a	Length of Channel (km)		Alteration Features		Location	
	Total	Modified	Type ^b	Date ^c	Distance (km) ^d	Elevation (m) ^e
1. Kaupuni Stream - I	37	3.7	1,3	1959, 1973	0	0
2. Mailiili Stream - I	34	4.3	1,3	1966, 1974	0	0
3. Ulehawa Stream - I	8	1.1	1,2,3	1963, 1966	0	0
4. Waikele Stream - C	195	5.2	2,3,4,6	1935, 1971	0	0
5. Waiawa Stream - C	93	4.3	2,3	1961, 1975	0	0
6. Waimalu Stream - C	46	4.9	1,2,3	1963, 1975	0	0
7. Kalauao Stream - C	13	1.2	2,3,4	1935, 1972	0	0
8. Aiea Stream - I	11	2.7	1,2,3,4	1961, 1973	0	0
9. Halawa Stream - C	40	4.1	1,3,4	1937, 1974	0	0
10. Moanalua Stream - I	44	15.1	1,2,3,4	1959, 1975	0	0
11. Kalihi Stream - C	18	4.8	3,4	1927, 1969	0	0
12. Kapalama Stream - I	9	9.0	1,2,3,4,5,6	1938, 1965	0	0
13. Nuuanu Stream - C	30	17.9	1,2,3,4,5	1932, 1975	0	0

Continued

Table 2 (Continued)

Stream - Class ^a	Length of Channel (km)		Alteration Features		Location	
	Total	Modified	Type ^b	Date ^c	Distance (km) ^d	Elevation (m) ^e
14. Makiki Stream - I	10	3.2	1,3,4,6	1920, 1972	0	0
15. Manoa Stream - C	34	8.3	1,2,3,4	1960, 1973	0	0
16. Waialaenui Stream - I	14	7.5	1,3,4	1961, 1975	0	0
17. Wailupe Stream - I	13	3.2	2,3,4	1930, 1955	0.1	0
18. Pia Stream - I	11	2.3	1,3	1964, 1969	0	0
19. Kuliouou Stream - I	4	1.6	1	1969, 1973	0	0
20. Waimanalo Stream - C	12	2.7	1,3,4	1963, 1976	0	0
21. Maunawili Stream - C	29	5.5	1,2,3	1964, 1974	0	0
22. Kawa Stream - C	5	2.3	1,2,3,6	1960, 1972	0	0
23. Kaneohe Stream - C	28	6.9	1,2,3	1964, 1971	0	0
24. Keaahala Stream - C	4	1.5	1,2,3	1966, 1968	0	0
25. Heeia Stream - C	11	1.5	1,2,3	1966, 1968	3.1	45
26. Kahaluu Stream - C	21	3.0	1,2,3	1963, 1972	0	0

Table 2 (Concluded)

Stream - Class ^a	Length of Channel (km)		Alteration Features		Location	
	Total	Modified	Type ^b	Date ^c	Distance (km) ^d	Elevation (m) ^e
27. Kaalaea Stream - C	4	0.1	3,4	1923, 1964	0	0
28. Kaipapau Stream - I	11	0.2	3,4	1932, 1964	0.2	0
29. Malaekahana Stream - C	30	2.4	2	ca. 1930	1.0	6
30. Oio Stream - I	10	2.0	2	1931, 1970	0	0
31. Makaleha Stream - C	23	1.3	2	1975	0	0

^aC = continuous, I = interrupted. See legend of Appendix A for definitions.

^b1 = lined channel, 2 = vegetation removed-channel realigned, 3 = elevated culvert, 4 = revetment, 5 = blocked or filled-in channel, 6 = extended culvert. See legend of Appendix B for definitions.

^cYear of earliest and most recent channel modification.

^dHorizontal distance from mouth to lowest point of channel modification.

^eElevation of lowest modification.

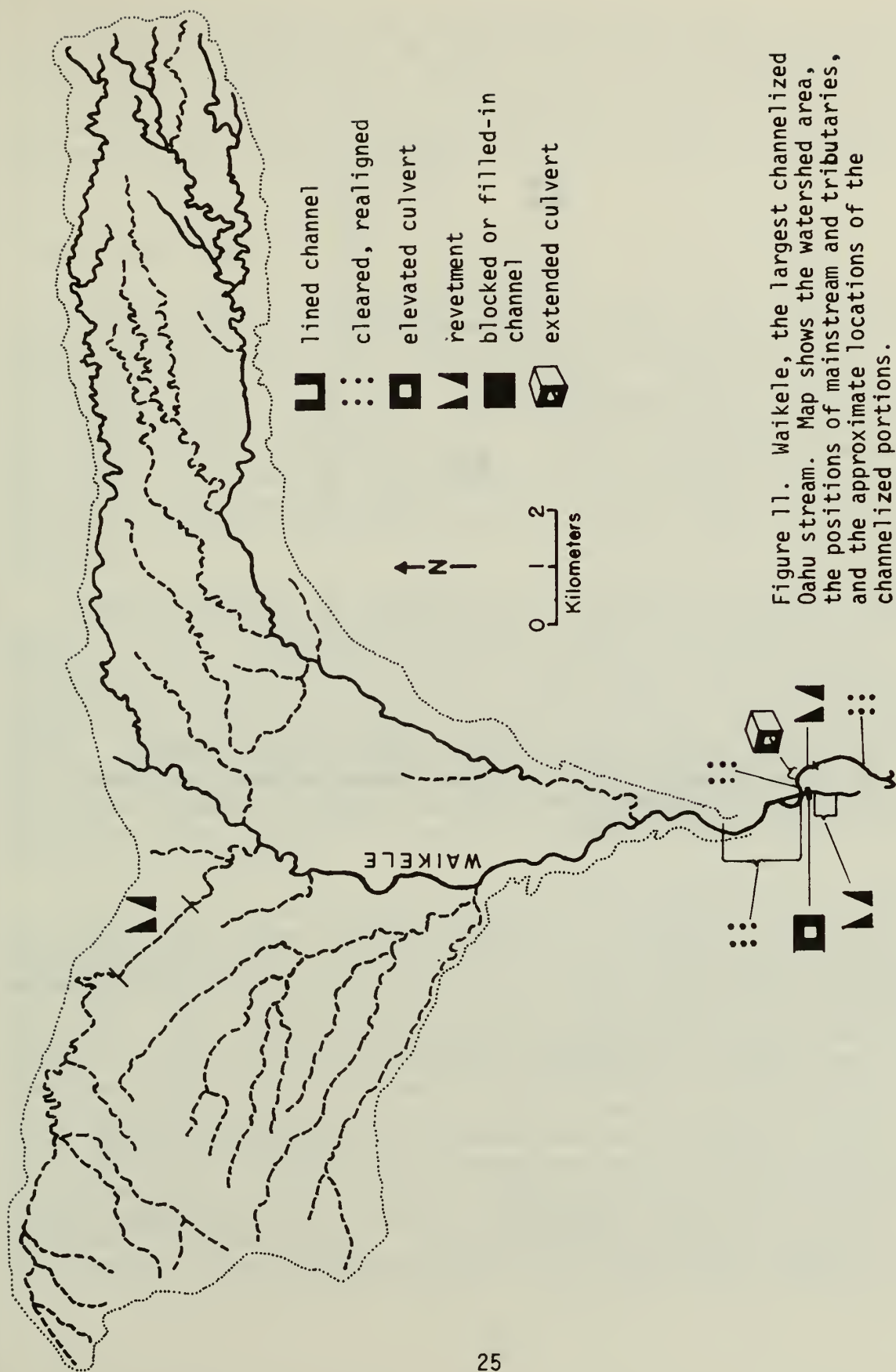


Figure 11. Waikaleo, the largest channelized Oahu stream. Map shows the watershed area, the positions of main stream and tributaries, and the approximate locations of the channelized portions.

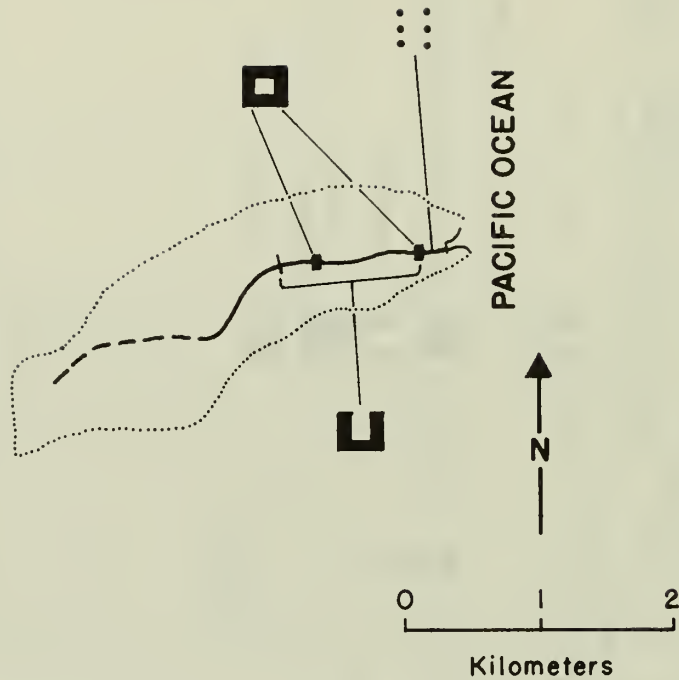


Figure 12. Keaahala, the smallest channelized Oahu stream. Map shows the watershed limits, the stream, and the approximate location of the channelized portions. See text and Figure 11 for symbol identification.

The altered sections of the channelized streams averaged 16% (range 2 - 100%) of total stream length. The water of one stream had been diverted into a storm drain and another was converted into a system of extended culverts in its upper and middle elevations. Fifty-seven percent of the streams have altered channels (discussed in detail in previous section), 58% have water exported, and all have roads crossing over them. There are, therefore, no physically pristine streams on Oahu.

FAUNA OF OAHU STREAMS

One of the purposes of this study was to determine the effects of channel modification on the occurrence and quantity of native fishes and crustaceans. Results of faunal inventories showed that of 23 species found on Oahu (Table 3), only seven (30%) were native to Hawaii. Although native crustaceans were well represented, relative abundances of native fishes were low in Oahu streams. A breakdown of the species as to habitat type (e.g., unaltered, altered) showed that because of exotic species predominance, there were more species in altered streams than in unaltered ones (22 vs. 12, Table 3). Lists of animals collected, their relative abundances, and approximate locations of collecting sites in altered streams are shown in Appendix B.

Relative abundances of faunal groups in altered and unaltered streams appear in Table 4. Data for altered streams come from collections made on natural sites above and below channelized sections, cleared/realigned, revetment, and concrete-lined channels. These comparisons indicate that exotic fishes predominate strongly in altered streams and that this group, together with exotic crustaceans, form 87% of the faunal biomass in altered streams. Important numbers and biomasses of native shrimps and fishes occur only in unaltered streams. Additional analysis was made on the macrofauna in altered streams according to habitat types (Table 5). Exotic species dominated all habitat types while native species were absent in areas with lined channels.

Results of this survey confirm the long-suspected absence from Oahu of the endemic o'opu alamoo (Lentipes concolor). The endemic o'opu nopili (Sicydium stimpsoni) was still present in a few unaltered Oahu streams (e.g., Waimea Stream) in low abundances, while the o'opu nakea (Awaous stamineus) was found in most streams, both altered and unaltered, but in low population densities. The o'opu naniha (Awaous genivittatus), which lives near stream mouths, was more abundant than the other three gobies in both altered and unaltered streams. As will be seen later, only on Oahu is the o'opu naniha found in high population densities. Among the exotic fishes, the wild guppy (Poecilia reticulata) was ubiquitous and most abundant. It was collected in 16 of 17 channelized streams sampled and represented 44% by number and 25% by weight of the total faunal collection from altered streams. Tilapia mossambica and the swordtail (Xiphophorus helleri) were also prominent in altered streams. The Chinese catfish (Clarias fuscus) was ubiquitous in cleared-realigned channels and revetments but absent in lined

Table 3. Distributions and Abundances of Macrofauna^a in Altered and Unaltered Streams^b on Oahu. Abundances:
 - = Absent, 0 = Rare/Occasional, ○ = Common, and ● = Abundant

Stream Fauna - Species	Unaltered	Altered
<u>Crustacea</u>		
Native		
<u>Atya bisulcata</u>	●	○
<u>Macrobrachium grandimanus</u>	●	●
Exotic		
<u>Macrobrachium lar</u>	○	○
<u>Procambarus clarkii</u>	-	●
<u>Pisces</u>		
Native		
<u>Awaous genivittatus</u>	○	○
<u>Awaous stamineus</u>	0	0
<u>Eleotris sandwicensis</u>	○	○
<u>Kuhlia sandwicensis</u>	0	0
<u>Sicydium stimpsoni</u>	0	-
Exotic		
<u>Cichlasoma sp.</u>	-	0
<u>Clarias fuscus</u>	-	0
<u>Cyprinus carpio</u>	-	0
<u>Gambusia affinis</u>	0	0
<u>Micropterus dolomieu</u>	-	0
<u>Misgurnus anguillicaudatus</u>	0	0
<u>Ophicephalus striatus</u>	-	0
<u>Poecilia latipinna</u>	-	0
<u>Poecilia mexicana</u>	-	●
<u>Poecilia reticulata</u>	○	●
<u>Poecilia vittata</u>	-	0
<u>Tilapia mossambica</u>	-	○
<u>Xiphophorus helleri</u>	○	●
<u>Xiphophorus maculatus</u>	-	0

^aFishes and decapod crustaceans.

^bBased on collections in 17 altered and six unaltered streams. Altered streams include Nos. 4, 5, 7, 9, 10, 11, 13, 14, 15, 17, 20, 21, 22, 23, 24, 25, and 26 on Fig. 10. Unaltered streams: Anahulu, Hakipuu, Kaukonahua, Waiahole, Waikane, and Waimea.

Table 4. Comparisons of Numbers and Weights Per 20 m X 1 m Station of Different Groups of Macrofauna in 17 Altered and 6 Unaltered Streams on Oahu (cf., Footnotes, Table 3). Native Species are Associated Mostly with Unaltered Streams, While Exotic Species Predominate in Altered Streams

Stream Fauna-Grouped	Unaltered		Altered	
	% No. (No.)	% Wt. (Wt., g)	% No. (No.)	% Wt. (Wt., g)
Native Crustaceans	53 (177)	13 (186.0)	7 (293)	2 (242.4)
Native Fishes	19 (64)	47 (646.8)	7 (262)	11 (1759.9)
Exotic Crustaceans	10 (32)	31 (424.5)	11 (434)	21 (3110.2)
Exotic Fishes	18 (62)	9 (126.2)	75 (2923)	66 (10094.1)

Table 5. Composition of Faunal Communities from Four Types of Habitats in Altered Streams on Oahu. No Native Species was Found in Lined Channels

Stream Fauna-Grouped	Natural Site Above and Below Channelization		Cleared- Realigned		Revetment		Lined Channel	
	% No	% Wt	% No	% Wt	% No	% Wt	% No	% Wt
Native Crustaceans	13	5	3	<1	2	<1	0	0
Native Fishes	3	8	5	9	17	13	0	0
Exotic Crustaceans	16	36	22	32	19	26	2	6
Exotic Fishes	68	51	70	58	62	60	98	94

channels. Among exotic Crustacea, Macrobrachium lar was ubiquitous in cleared-realigned channels, rare in revetments, and absent in lined channels. The crayfish (Procambarus clarkii) was distributed widely.

As noted earlier (METHODS), species abundance and distribution data presented here do not characterize the entire stream ecosystem. Among crustaceans, for example, the native prawn (Macrobrachium grandimanus) was found only in lower stream reaches, whereas the native shrimp (Atya bisulcata) was characteristic of upstream areas. The introduced prawn (Macrobrachium lar) ranged from brackish coastal habitats to upstream areas, often attaining greatest abundances in the midreaches of streams. Exotics were collected in both altered and unaltered streams.

STREAM AND FAUNA INVENTORY: OTHER ISLANDS

MAUI

Maui, the second largest island in the state, measures 77 by 42 km at its extreme dimensions and has an area of 1,886 km² (Sahara et al. 1967). It originated from two major volcanoes. Puu Kukui, West Maui, emerged in part from the ocean in Pliocene and early Pleistocene. Haleakala, East Maui, emerged in early and middle Pleistocene, with renewed volcanic activity in middle to late Pleistocene and Recent time (Stearns and MacDonald 1942). West Maui, the older of the two parts of the island, rises to 1,764 m altitude and is deeply eroded. East Maui attains 3,056 m and features relatively smooth slopes on its western and northern sides. The climate varies with altitude and to a lesser extent with position to windward or leeward. Large increases in rainfall occur over short distances when moving from low to high elevations or going from leeward to windward areas. In West Maui, the climate varies from dry and sunny Lahaina where the median annual rainfall is 40 cm/yr to 1,020 cm/yr at Puu Kukui, the highest point. The climate on the leeward slopes of Haleakala (East Maui) is warm and sunny with a median annual rainfall of 50 cm/yr; the windward and eastern slopes have a median annual rainfall up to 760 cm/yr (Sahara et al. 1967). Annual mean air temperature for the whole island at 60 m elevation is 23° C (22-25° C).

Ninety-six perennial streams have been recognized and are listed in Appendix A. Fifty-eight percent of these streams are continuous, the rest are interrupted. Seven streams (7%) were found to have altered channels, four in Lahaina District and three in Wailuku District. All seven channelized streams are usually dry at lower elevations because normal flows are diverted and exported from the drainages. Discharge to the ocean occurs irregularly, mainly during periods of heavy winter rainfall. The locations of these altered streams are shown in Fig. 13, and their features are summarized in Table 6.

Iao Stream, Wailuku District, is the largest of the altered streams on the basis of stream length and watershed area. Kauaula Stream, Lahaina District, is the smallest. Watershed limits, stream channels, longitudinal gradient of mainstream, and the approximate locations of the channelized portions in each stream are shown in Appendix B.

A total of 5 km of modified channels occurs among the seven altered streams. Modified sections of the altered streams averaged 3% (range <1 -

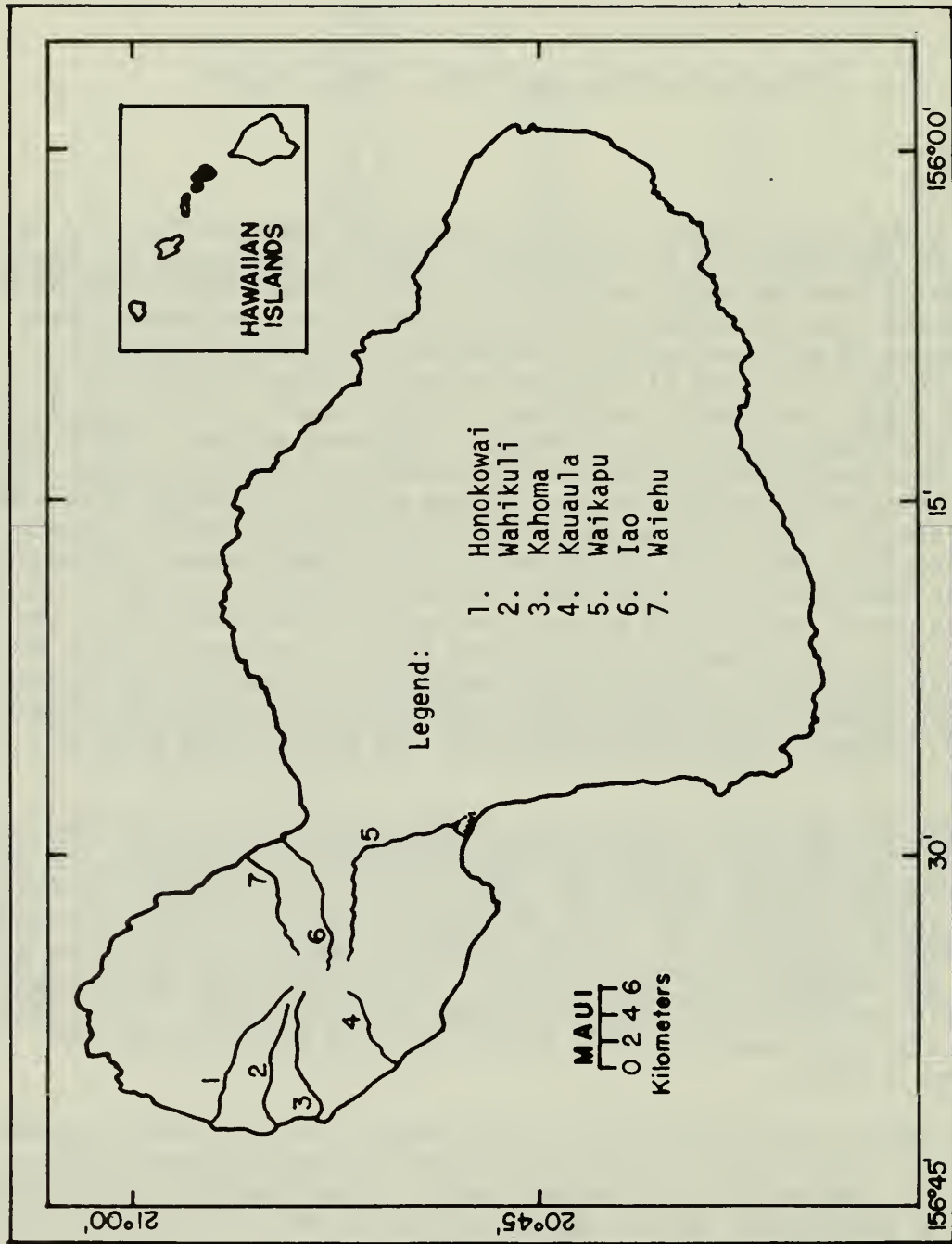


Figure 13. Location map for seven Maui streams having modified channels. Percentage of streams altered = $7/96 = 7\%$.

Table 6. Some Physical Characteristics of the Seven Maui Streams Having Channel Modifications. See Fig. 13 for Locations

Stream - Class ^a	Length of Channel (km)		Alteration Features		Location	
	Total	Modified	Type ^b	Date ^c	Distance (km) ^d	Elevation (m) ^e
1. Honokowai Stream - I	20	0.4	4	1962, 1964	0	0
2. Wahikuli Stream - I	19	0.4	4	1971	0	0
3. Kahoma Stream - C	25	1.0	3,4	ca. 1930, 1957	0	0
4. Kauaula Stream - C	10	0.3	1	1971	0	0
5. Waikapu Stream - C	25	2.8	2	1937, 1970	1.0	1
6. Iao Stream - C	38	0.2	1,3,4	1949	0.7	9
7. Waiehu Stream - C	23	0.1	3	1959	0.2	6

^aC = continuous, I = interrupted. See legend of Appendix A for definitions.

^b1 = lined channel, 2 = vegetation removed-channel realigned, 3 = elevated culvert, 4 = revetment. See legend of Appendix B for definitions.

^cYear of earliest and most recent channel modification.

^dHorizontal distance from mouth to lowest point of channel modification.

^eElevation of lowest modification.

11) of total stream length. The relative "abundance" of each type of channel modification expressed as a percentage of the 5 km total is as follows:

Cleared and realigned - 54%;
Revetment - 34%;
Lined channel - 8%;
Elevated culverts - 4%.

Aside from the 7% channelized streams on Maui, diversions are found in 59% and road crossings on 96%. One percent of Maui streams (= one stream) is physically pristine.

Water from four Lahaina District streams has been diverted for agricultural use for a considerable time (e.g., Kahoma Stream, ca. 40 yrs.), making them dry at mid and low elevations. Collections from those streams (Honokowai, Wahikuli, Kahoma, and Kauaula), taken above the diversion points (elevations between 305 and 474 m), revealed an absence of fishes and crustaceans. Water was present at the mouths of these "dry" streams, due to tidal influence. A slight return flow of water from irrigation ditches in Wahikuli contained only Poecilia reticulata. On the other hand, nearby Ukumehame Stream is also dewatered, but its diversion is at a lower elevation (73 m). Collections above its diversion point contained two species of decapod crustaceans and three species of fishes. Included were the endemic shrimp, opae kalaole (Atya bisulcata), and the endemic goby, o'opu nopili (Sicydium stimpsoni). Lists of biota collected and approximate locations of collecting sites are shown in Appendix B.

Faunal inventory of Maui streams showed that there were more species in unaltered than in altered streams (Table 7), a condition opposite to that of Oahu. Moreover, more native species were found in unaltered than in altered streams. Population densities of native fishes were high in East Maui but low in West Maui streams. The o'opu nopili had high population density, o'opu nakea had medium density, but the o'opu naniha was not collected (Table 7). As on Oahu, the guppy (Poecilia reticulata) was widely distributed; it was collected in six of the seven streams sampled. At least one exotic species was present in all streams sampled.

MOLOKAI

The island of Molokai is the State's fifth largest island (673 km²), measuring 61 by 16 km at its extreme dimensions. In geologic time, Molokai built upward from the sea during the Tertiary, possibly early Pleistocene (Stearns 1946, Stearns and MacDonald 1947). Molokai was formed by two volcanic domes, but only one remains a dominant feature, East Molokai, which rises to 1,515 m. West Molokai is characterized by rolling arid land rising to 721 m, while East Molokai is mountainous with many deep gulches and canyons. Mean annual air temperature of Molokai as a whole is 24° C with seasonal fluctuations ranging from 18 to 29° C. Median annual rainfall has

Table 7. Distributions and Abundances of Macrofauna^a in Altered and Unaltered Streams^b on Maui. Abundances:
 - = Absent, 0 = Rare/Occasional, ○ = Common, and ● = Abundant

Stream Fauna - Species	Unaltered	Altered
<u>Crustacea</u>		
Native		
<u>Atya bisulcata</u>	●	○
<u>Macrobrachium grandimanus</u>	●	○
Exotic		
<u>Macrobrachium lar</u>	○	-
<u>Procambarus clarkii</u>	-	0
<u>Pisces</u>		
Native		
<u>Awaous genivittatus</u> ^c	0	0
<u>Awaous stamineus</u>	○	0
<u>Eleotris sandwicensis</u>	○	-
<u>Kuhlia sandwicensis</u>	0	0
<u>Lentipes concolor</u>	0	-
<u>Sicydium stimpsoni</u>	●	-
Exotic		
<u>Clarias fuscus</u>	-	0
<u>Poecilia reticulata</u>	●	●
<u>Tilapia mossambica</u>	0	0

^aFishes and decapod crustaceans.

^bBased on collections in four unaltered (Waihee, Honokohau, Ukumehame, and Hanawi) and three altered (Iao, Waiehu, and Wahikuli) streams.

^cWas not collected in this survey but collected previously by John A. Maciolek.

great areal variability: western and central Molokai receive from 38 to 76 cm per year depending upon elevation, while East Molokai receives from 38 to over 381 cm per year (Baker et al. 1968, Swain 1973).

Thirty-seven perennial streams have been recognized and are listed in Appendix A. All are on East Molokai. Only 43% of these streams are continuous. Only one, interrupted Kamalo Stream on the southeast side of Molokai, has been altered with an elevated culvert. Its location is shown in Fig. 14 and its features are summarized as follows (for explanation of symbols, see Table 6):

Stream - Class	<u>Length of Channel (km)</u>		<u>Alteration Features</u>		<u>Location</u>	
	Total	Modified	Type	Date	Distance (km)	Elevation (m)
Kamalo Stream - I	19	0.1	2	1930	0.3	0

Watershed limits, stream channels, longitudinal gradient of mainstream, and the approximate location of the channelized portion are shown in Appendix B. As a whole, streams in Molokai appear to have fared better than those in other islands. Only 3% of streams have channel alterations, 12% are diverted, and 38% have road crossings. Molokai has the largest percentage of physically pristine streams in the State - 49%.

Kamalo Stream is dry at the low and middle elevations. Collections were, however, made in two unaltered streams; Honouliwai Stream, which is in the general vicinity of Kamalo Stream, and Halawa Stream at the eastern end of Molokai. Nine decapod crustacean and fish species were collected (Table 8), eight (89%) of which were native species. Unlike Oahu, but like East Maui streams, native fish densities (except the endemic goby, Lentipes concolor) were high. The exotic Tahitian prawn (Macrobrachium lar) was found in both streams. The indigenous o'opu naniha was not collected in either Honouliwai or Halawa streams.

HAWAII

The island of Hawaii is the largest (10,438 km²) in the state, measuring 150 by 122 km at its extreme dimensions. It is the youngest geologically, having emerged from the ocean between late Pleistocene and Recent time (Zimmerman 1948). It is the result of five volcanoes (Baker et al. 1965), three of which are currently or recently active. The peaks of these volcanoes range in altitude from a few hundred to 4,206 m, resulting in about 80 percent of the island being 305 m in elevation. Topography is

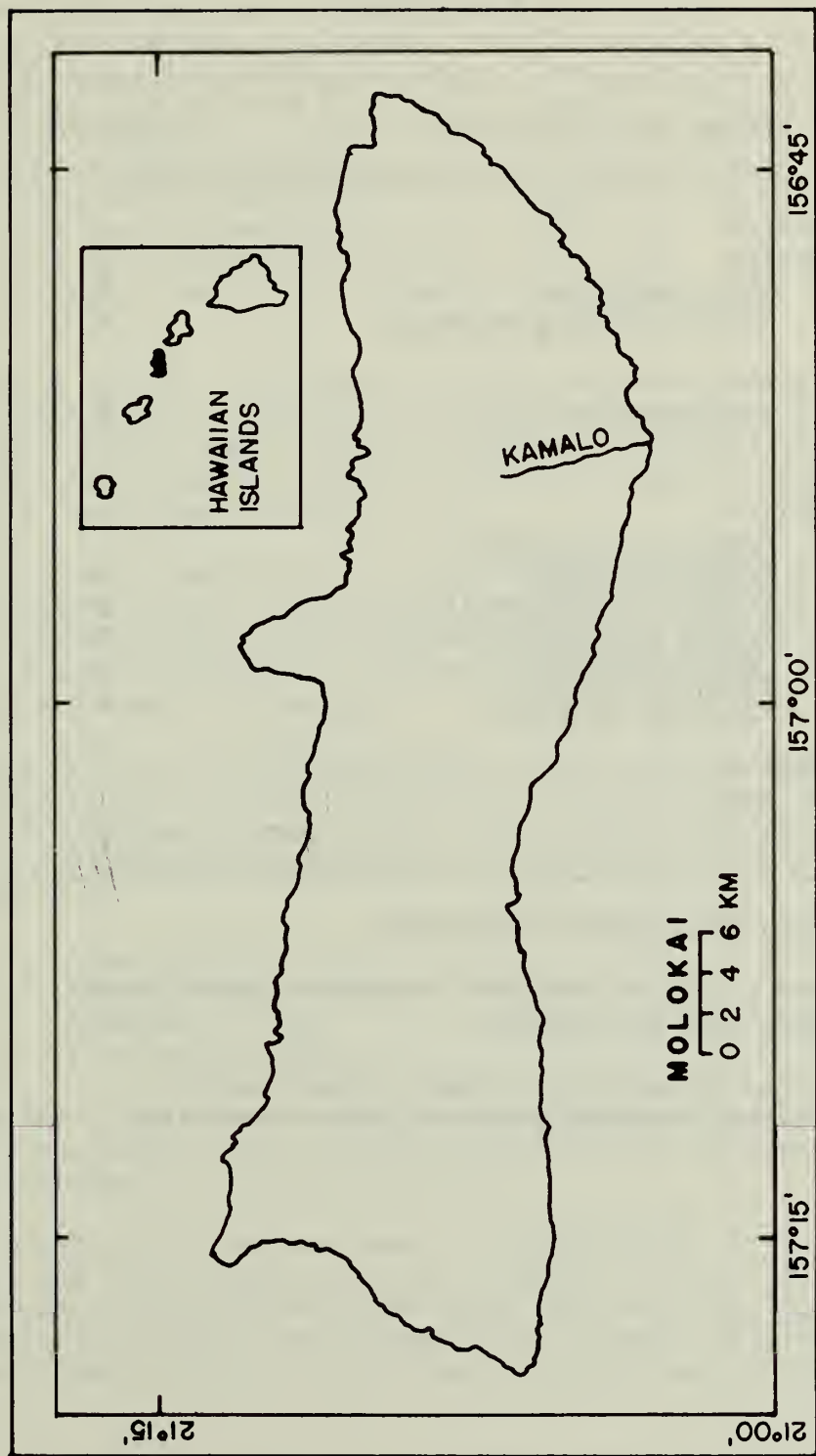


Figure 14. Location map for Kamalo Stream, the only stream with an altered channel on Molokai. Percentage of streams altered = $1/37 = 3\%$.

Table 8. Distributions and Abundances of Macrofauna^a
in Unaltered Streams^b on Molokai. Abundances:
- = Absent, 0 = Rare/Occasional, ○ = Common,
and ● = Abundant

Stream Fauna - Species	Abundance
Crustacea	
Native	
<u>Atya bisulcata</u>	○
<u>Macrobrachium grandimanus</u>	○
Exotic	
<u>Macrobrachium lar</u>	○
Pisces	
Native	
<u>Awaous genivittatus</u> ^c	-
<u>Awaous stamineus</u>	○
<u>Eleotris sandwicensis</u>	○
<u>Kuhlia sandvicensis</u>	○
<u>Lentipes concolor</u>	0
<u>Sicydium stimpsoni</u>	○
Exotic	
none	

^aFishes and decapod crustaceans.

^bBased on collections made in two unaltered streams (Honouliwai and Halawa).

^cWas not collected in subject streams but was observed in Wailau Stream by John A. Maciolek.

related to lava flows from the various volcanoes. It is generally smooth and sloping, uncarved by geologic erosion. However, at the northern corner of the island, the old Kohala mountains have been eroded into cliffs and canyons where they face the northeast trades. Extremes of rainfall and terrain produce a variety of climates, from the very humid rain forests on the windward slopes to the dry, hot desert-like climate of the leeward slopes. Rainfall ranges from 25 to 760 cm annually, depending upon location and altitude. Island-wide average annual rainfall is 130 cm. There is a broad range of air temperatures caused by the high mountains. At sea level, the annual temperature averages 24° C; the summits of the two highest mountains have freezing temperatures most of the year. All perennial streams are on the northeastern portion of the island. With few exceptions they are limited to the windward slopes of Mauna Kea and the Kohala mountains.

On Hawaii Island, 123 perennial streams have been recognized and are listed in Appendix A. Fifty-seven percent of these streams are continuous. Four streams (3%) have been altered. Three of the altered streams are interrupted. The locations of these streams are shown in Fig. 15 and their features are summarized in Table 9.

Wailoa River, Puna District, is the largest on the basis of stream length and watershed area. Lamimaumau Stream, north of Kamuela, is the smallest. The watershed limits, stream channels, mainstream, longitudinal gradients, and the approximate locations of the channelized portions of each stream are shown in Appendix B.

A total of 4 km of modified channel exists among the four altered streams. Modified sections of the altered streams averaged 7% (range 0.6 - 12%) of their combined channel length. The relative "abundance" of each type of channel modification expressed as percentage of the 4 km total is as follows:

- Lined channel - 44%;
- Cleared and/or realigned - 31%;
- Revetment - 23%;
- Elevated culvert - 2%.

Apart from the 3% of streams with channel alterations, water is diverted from 60% of the Hawaii Island streams, and 79% have road crossings. Only 11% of the streams are physically pristine.

Biological collections were made in eight streams in Puna, South Hilo, North Hilo, and North Kohala districts of Hawaii. Two of the streams are channelized but only one, the Wailoa River, has been significantly altered. The six unaltered streams are representative of Hawaii streams having continuous strong waterflow through deeply eroded, heavily vegetated gulches.

Eleven species of fishes and crustaceans were collected, eight (73%) of these are native to Hawaii. In another study (Timbol 1977), 11 species

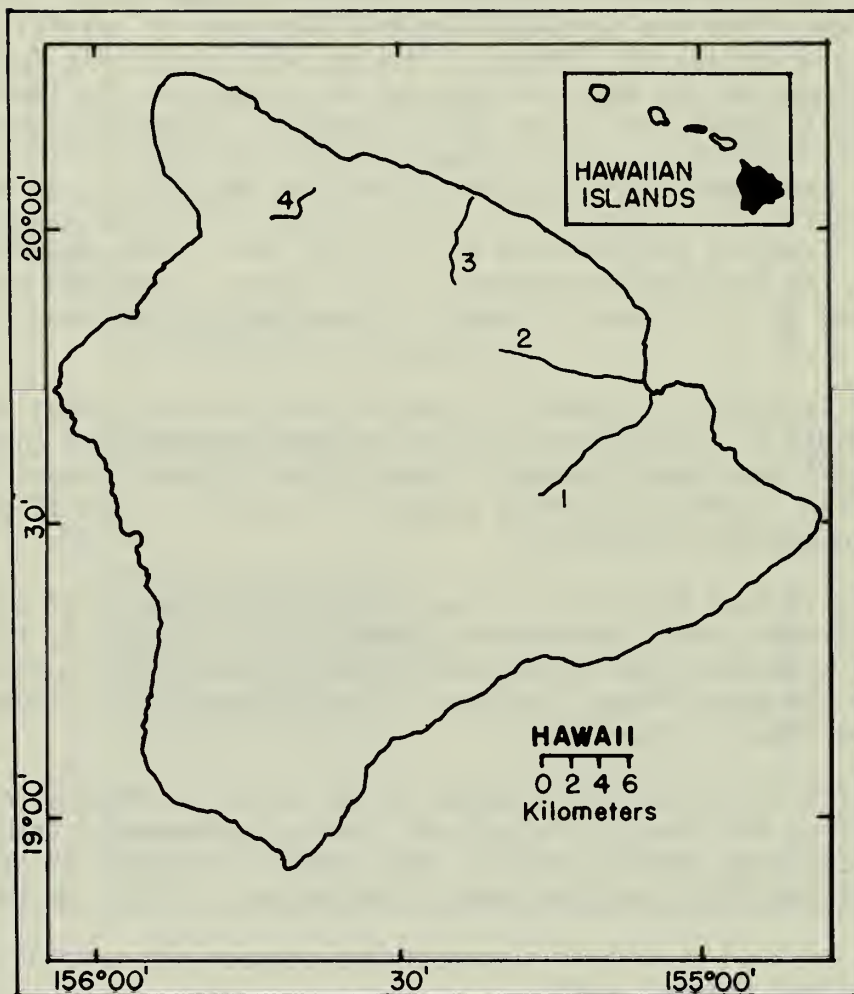


Figure 15. Location map for four Hawaii streams having modified channels. Percentage of streams altered = $4/123 = 3\%$.

Legend:

1. Wailoa River
2. Pukihae Stream
3. Papuaa Stream
4. Lamimaumau Stream

Table 9. Some Physical Characteristics of the Four Hawaii Streams Having Channel Modifications. See Fig. 15 for Locations

Stream - Class ^a	Length of Channel (km)		Alteration Features		Location	
	Total	Modified	Type ^b	Date ^c	Distance (km) ^d	Elevation (m) ^e
1. Wailoa River - I	26	3.2	1,2,4	ca. 1920, 1962	0.8	0.3
2. Pukihae Stream - C	16	0.1	3	ca. 1910	<0.1	0
3. Papuaa Stream - I	5	0.1	3,4	ca. 1930, 1972	2.5	330
4. Lamimaumau Stream - I	5	0.5	1	1968, 1969	16.5	866

^aC = continuous, I = interrupted. See legend of Appendix A for definitions.

^b1 = lined channel, 2 = vegetation removed-channel realigned, 3 = elevated culvert, 4 = revetment. See legend of Appendix B for definitions.

^cYear of earliest and most recent channel modification.

^dHorizontal distance from mouth to lowest point of channel modification.

^eElevation of lowest modification.

of fishes and decapod crustaceans were also collected in Wailoa Stream (Waipio Valley). There was no significant difference in the number of species present in altered and unaltered streams (see Table 10). However, population density of stream macrofauna was higher in unaltered streams than in altered ones. The population densities were high for o'opu nopili, especially in Niulii and Waikama streams, medium for o'opu nakea, while the o'opu alamoo was not collected during this study. The indigenous o'opu naniha was of medium population density near the mouth of Wailoa River. The native crustaceans, A. bisulcata and M. grandimanus, the introduced crustacean, M. lar, and the introduced guppy, P. reticulata, were widespread in Hawaii streams. As was the case in the other islands, exotics were collected in all streams sampled.

KAUAI

Kauai, the fourth largest island (1,437 km²) measures 54 by 40 km at its extreme dimensions. Geologically, it is the oldest, having emerged from the ocean during the Tertiary Period. The island contains rugged mountains and canyons at its center. Mount Waialeale is the dominant feature of the island, with its Kawaikini Peak the highest point at 1,587 m. Kauai's climate is generally mild. Rainfall is relatively high in windward areas but minimal in leeward areas; Mt. Waialeale receives over 1,000 cm/yr, while Kekaha, about 38 km leeward, receives only about 50 cm/yr (Foote et al. 1972). Mean annual air temperature is 24° C in the lowlands and 15° C at Kokee (elevation 1,067 m).

Fifty-six perennial streams have been recognized in Kauai and are listed in Appendix A. Seventy-seven percent of the Kauai streams are continuous, the highest percentage in the State. Twelve of these streams (21%) have altered channels. The locations of these altered streams are shown in Fig. 16 and their features are summarized in Table 11.

Waimea, a dendritic drainage on the southwest side of the island, is the largest on the basis of stream length and watershed area. Waikoko, in the north, is the smallest altered stream. The watershed limits, stream channels, mainstream longitudinal gradients, and the approximate locations of the channelized portions of each stream are shown in Appendix B. Modified sections of the altered streams averaged 1% (range 0.1 - 13). A total of 8 km of modified channels occur among the 12 altered streams. Three types of channel modifications occur; the relative "abundance" of each type of channel modification expressed as a percentage of the 8 km total is as follows:

Cleared and realigned - 51%;
Revetment - 35%;
Elevated culvert - 14%.

There are no lined channels among the altered Kauai streams. In addition to the 21% stream channel alterations on Kauai, 45% have water diverted from

Table 10. Distributions and Abundances of Macrofauna^a in Altered and Unaltered Streams^b on Hawaii. Abundances:
 - = Absent, 0 = Rare/Occasional, ○ = Common, and ● = Abundant

Stream Fauna - Species	Unaltered	Altered
<u>Crustacea</u>		
Native		
<u>Atya bisulcata</u>	●	-
<u>Macrobrachium grandimanus</u>	●	○
Exotic		
<u>Macrobrachium lar</u>	●	○
<u>Pisces</u>		
Native		
<u>Awaous genivittatus</u>	-	○
<u>Awaous stamineus</u>	○	○
<u>Eleotris sandwicensis</u>	○	○
<u>Kuhlia sandwicensis</u>	○	○
<u>Lentipes concolor</u> ^c	○	-
<u>Sicydium stimpsoni</u>	●	○
Exotic		
<u>Gambusia affinis</u>	-	○
<u>Poecilia reticulata</u>	●	●
<u>Xiphophorus maculatus</u>	-	○

^aFishes and decapod crustaceans.

^bBased on collections made in two altered and six unaltered streams. Altered streams: Pukihae and Wailoa River (Alenaio tributary at Waialama Canal). Unaltered streams: Aamakao, Honolii (and Kaiwiki), Kolekole, Niulii, Paheehee, and Waikama.

^cNot collected in this study but previously obtained by John A. Maciolek.

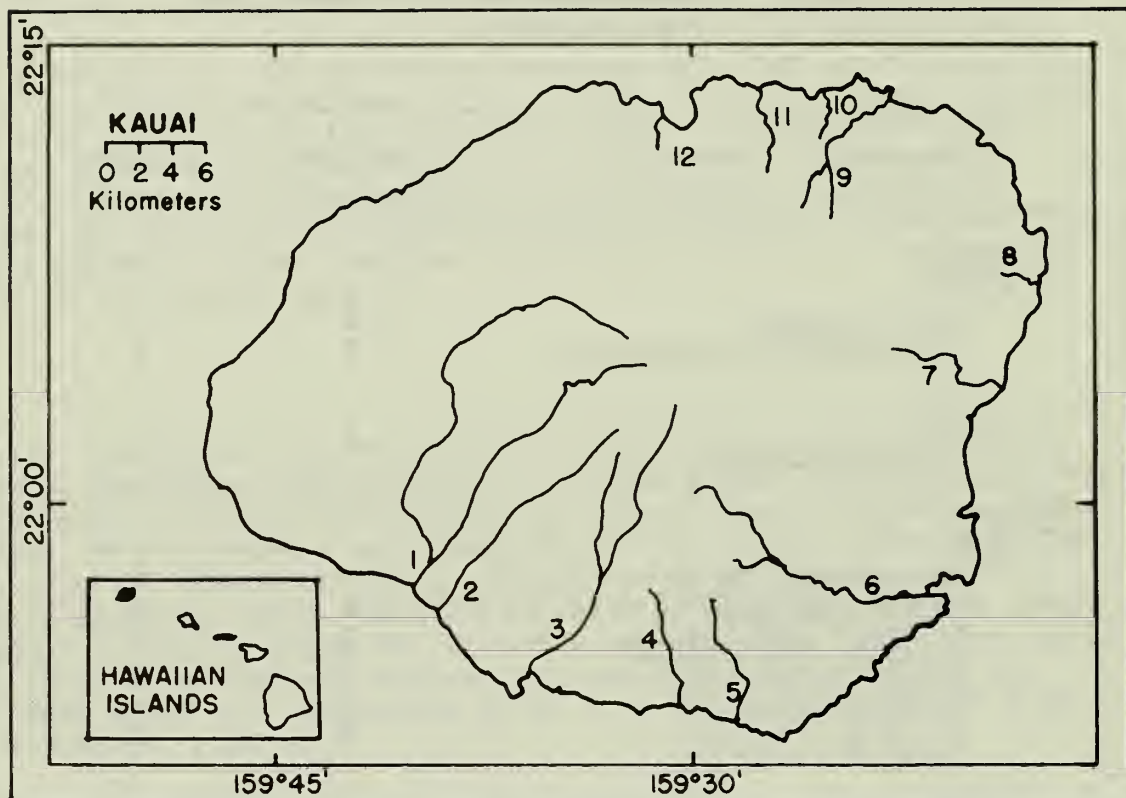


Figure 16. Location map for the 12 Kauai streams having modified channels. Percentage of streams altered = $12/56 = 21\%$.

Legend:

1. Waimea River
2. Waipao Stream
3. Hanapepe Stream
4. Lawai Stream
5. Waikomo Stream
6. Huleia Stream
7. Konohiki Stream
8. Kumukumu Stream
9. Kilauea Stream
10. Puukumu Stream
11. Anini Stream
12. Waikoko Stream

Table 11. Some Physical Characteristics of the Twelve Kauai Streams Having Channel Modifications. See Fig. 16 for Locations.

Stream - Class ^a	Length of Channel (km)		Alteration Features		Location	
	Total	Modified	Type ^b	Date ^c	Distance (km) ^d	Elevation (m) ^e
1. Waimea River - C	373	2.0	4	1952, 1953	0	0
2. Waipao Stream - C	33	0.1	4	1948	0.5	6
3. Hanapepe Stream - C	121	1.0	4	1962, 1963	0.7	6
4. Lawai Stream - C	27	0.6	2	1975, 1976	0.9	12
5. Waikomo Stream - C	28	0.1	3,4	1930, 1968	0.3	6
6. Huleia Stream - C	102	0.1	3	1937	12.0	122
7. Konohiki Stream - C	20	2.5	2	1946, 1948	0	0
8. Kumukumu Stream - C	3	0.6	2,3	1920, 1958	0	0
9. Kilauea Stream - C	56	0.1	3	1973	2.2	85
10. Puukumu Stream - C	7	0.1	3	1973	1.3	73
11. Anini Stream - I	14	0.1	3	1968	3.2	98
12. Waikoko Stream - C	2	0.6	2	1930	0.1	0

^aC = continuous, I = interrupted. See legend of Appendix A for definitions.

Continued

Table 11 (Concluded).

b2 = vegetation removed-channel realigned, 3 = elevated culvert, 4 = revetment. See legend of Appendix B for definitions.

cYear of earliest and most recent channel modification.

dHorizontal distance from mouth to lowest point of channel modification.

eElevation of lowest modification.

their channels, and 68% have road crossings. Kauai, however, is second only to Molokai in the proportion of physically pristine streams (32%).

Survey results showed that of the 16 species collected, seven (44%) are native to Hawaii (Table 12). In another study (Timbol 1977), eighteen species were collected from Wainiha, Hanalei, and Wailua Rivers, all unaltered Kauai streams. Comparison of altered and unaltered streams showed little difference in species richness or abundance of macrofauna. This may be due to the relatively innocuous channel modifications in Kauai streams, cleared and/or realigned channels (51%) being closest to unaltered conditions compared to other types of modifications. Exotics were also found in all streams sampled. (In contrast, exotic species in Oahu streams were predominant both in number and biomass in altered streams while native species were predominant in unaltered streams). In Kauai the o'opu nakea was found in more streams and in higher population density than the o'opu nopili. The o'opu naniha had low population density, while the o'opu alamoo was not collected during this study. The swordtail, Xiphophorus helleri, was ubiquitous in Kauai.

Table 12. Distributions and Abundances of Macrofauna^a in Altered and Unaltered Streams^b on Kauai. Abundances:
 - = Absent, 0 = Rare/Occasional, ● = Common, and
 ● = Abundant

Stream Fauna - Species	Unaltered	Altered
<u>Crustacea</u>		
Native		
<u>Atya bisulcata</u>	●	●
<u>Macrobrachium grandimanus</u>	●	●
Exotic		
<u>Macrobrachium lar</u>	0	0
<u>Procambarus clarkii</u>	0	0
<u>Pisces</u>		
Native		
<u>Awaous genivittatus</u>	0	0
<u>Awaous stamineus</u>	●	●
<u>Eleotris sandwicensis</u>	0	0
<u>Kuhlia sandwicensis</u>	●	●
<u>Lentipes concolor</u> ^c	-	-
<u>Sicydium stimpsoni</u>	●	●
Exotic		
<u>Clarias fuscus</u>	0	0
<u>Lepomis macrochirus</u>	0	-
<u>Micropterus dolomieu</u>	0	-
<u>Misgurnus anguillicaudatus</u>	0	0
<u>Poecilia reticulata</u>	●	0
<u>Tilapia mossambica</u>	0	0
<u>Xiphophorus helleri</u>	●	●

^aFishes and decapod crustaceans.

^bBased on collections made in ten altered and seven unaltered streams. Altered streams include Nos. 1, 3, 4, 5, 6, 7, 8, 9, 10, and 11 on Fig. 16. Unaltered streams: Aakukui, Wailua at Opaekaa and Kalama tributaries, Wainiha, Hanalei, Manoa, Waioli, and Limahuli.

^cNot collected in this study but previously obtained by John A. Maciolek.

PHYSICOCHEMICAL CHARACTERISTICS OF HAWAIIAN STREAMS

This section considers some physicochemical features and discharges of streams. Most of the data were obtained from USGS and Hawaii Department of Health publications. Additional data (e.g., water temperature from different types of channel alterations on Oahu) were obtained in this study.

SURFACE WATER DISCHARGES

By continental standards, even the largest of Hawaiian streams is minute. For example, the annual mean discharge of the Mississippi River measured near Vicksburg, Mississippi, is 19,633 times that of the largest river (Wailuku) in Hawaii (data from Leopold and Maddock 1953 and USGS 1977). Hawaiian streams are, however, of the magnitude of other Pacific high island streams.

Comparing the surface water discharges of three of the largest streams from each island of the State, Hawaii showed the highest mean for water year 1976 followed by Kauai. Maui and Oahu have about equal annual mean discharges while Molokai has the lowest (see also Table 13). Several of the perennial streams in each of the five islands surveyed do not discharge to the sea at various times of the year (see METHODS for definitions). In extreme cases, naturally strong, continuous flowing streams are rendered artificially interrupted due to diversions (e.g., Kahoma, Wahikuli, and Honokowai on West Maui). Water is diverted in more than half of Hawaii's streams with Hawaii having 60%, Maui and Oahu with 59% each, Kauai, 46%, and Molokai with 14 %. Appendix A shows which streams are diverted.

Kauai is the island with the largest percentage of its streams continuous, followed by Maui, Hawaii, Oahu, and Molokai in decreasing order. Additional water discharge data - annual mean, minimum and maximum discharges, USGS gaging station identification numbers, and presence of diversions above gaging stations - are presented in Appendix C.

COMPOSITION OF HAWAIIAN STREAM WATERS

Among the five major islands in the State, water in Oahu streams contains the highest total dissolved solids (Table 14). Maui (as represented by West Maui) and Kauai waters have the next highest dissolved solids (70% and 67% of Oahu waters, respectively) followed by Molokai (61%) and Hawaii

Table 13. Surface Water Discharges of the Three Largest Streams from Each of the Five Islands of Hawaii for Water Year 1976 (October 1975 - September 1976). Adapted from USGS (1977). Discharge Data are Annual Means and Instantaneous Maxima and Minima.

Island Stream	Discharge (m ³ /s)			Gaging Station No. and Remarks
	Mean	Maximum	Minimum	
A. Hawaii				
1. Honolii	3.9	100.3	0.3	16717000. No diversion above station.
2. Pohakupuka	0.9	11.0	0.02	16717800. No diversion above station.
3. Wailuku	9.7	271.0	0.2	16704000. Diversions above station.
(Average)	(4.8)	(127.4)	(0.2)	
B. Maui				
1. Honokohau	0.7	6.6	0.3	16620000. No diversions above station.
2. Palikea	1.2	21.5	0.001	16501000. No diversions above station.
3. W. Wailuku	0.6	31.2	0.1	16518000. No diversions above station.
(Average)	(0.8)	(20.0)	(0.1)	
C. Oahu				
1. Kahana	0.7	9.1	0.3	16296500. Diversion above station.
2. Waikele	1.1	27.4	0.04	16213000. Diversions above station.
				Continued

Table 13 (Concluded)

Island Stream	Discharge (m ³ /s)			Gaging Station No. and Remarks
	Mean	Maximum	Minimum	
3. Waimea	0.5	22.0	0	16330000. Kamananui Trib., no diversions above station.
(Average)	(0.8)	(19.5)	(0.1)	
D. Kauai				
1. Hanalei	5.3	73.3	0.7	16103000. Diversions above station.
2. Wailua	5.8	82.1	0.2	16060000, 16071000. South Fork Wailua Trib. plus North Fork Wailua Trib., several diversions above gaging stations.
3. Waimea	2.0	150.4	0.3	16031000, 16036000. Waimea mainstream plus Makaweli Trib., several diversions above stations.
(Average)	(4.4)	(101.9)	(0.4)	
E. Molokai				
1. Halawa	0.6	12.4	0.1	16400000. No diversion above station.
2. Pelekunu	0.4	3.4	0.1	16404000. No diversion above station.
3. Waikolu	0.2	4.3	0.1	16408000. Diversion above station.
(Average)	(0.4)	(6.7)	(0.1)	

Table 14. Dissolved Inorganic Ions and Selected Physicochemical Parameters of Hawaiian Streams^a

Parameters	Annual Mean in mg/l				
	Hawaii ^b	Maui ^c	Oahu ^d	Kauai ^e	Molokai ^f
Calcium	2.0	9.0	9.1	5.7	6.5
Magnesium	1.6	3.6	7.2	6.2	2.3
Sodium	4.1	6.8	17.6	8.6	8.3
Potassium	1.0	0.9	1.3	0.8	1.0
Alkalinity as CaCO ₃	7.8	31.3	43.0	34.4	22.3
Sulfate	2.7	7.3	9.4	3.5	5.9
Chloride	6.0	9.1	25.4	13.4	10.9
Dissolved Solids (sum of constituents)	31.0	78.7	112.2	75.5	68.5
pH (units)	6.2	7.5	7.2	7.3	7.2
Conductivity (μmhos)	43.0	107.4	180.0	131.0	93.0

^aData from USGS (1976) ranging from two readings/year in most streams to 10 in a few.

^bHawaii Island streams (Kohala District only): Alakahi, Lamimaumau (Kohakohau), and Waikoloa.

^cMaui Island streams (West Maui only): Honokohau, Iao, Kahakuloa, and Olowalu.

^dOahu Island streams: Helemano, Kalauao, Kalihi, Kaluanui, Kaneohe, Kaukonahua, Makaha, Makiki, Manoa, Maunawili, Moanalua, Nuuanu, Opaepa, Punaluu, Waiawa, Waikane, Waikele, Waimanalo, and Waimea.

^eKauai Island streams: Anahola, Hanalei, Hanapepe, Huleia, Lawai, Wailua, Waimea, and Wainiha.

^fMolokai Island streams: Halawa, Pelekunu, and Waikolu.

(34%) as represented by Kohala streams. Water temperature varies from 14 to 22° C depending upon season and elevation. In general, there is a direct relationship between total dissolved solids in water and its conductivity. Conductivity values obtained are as expected; water in Oahu streams has the highest conductivity, followed by Kauai, Maui, Molokai, and Hawaii. These values are well within the standards set by the Department of Health (1977).

In comparison with other natural waters, major cation contents of Hawaiian streams are nearer those of water from igneous rocks than those of rivers. Water in Hawaiian streams has more sodium than the mean fresh water of the world's river systems, as given by Clarke (in Hutchinson 1957) and water from igneous rocks as compiled by Conway (in Hutchinson 1957). This condition (Na > Ca > Mg > K, Table 15) is not unusual due to the insularity of Hawaii. By contrast, the proportions are Ca > Mg > Na > K in the world's river systems (Hutchinson 1957).

Table 15. Mean Equivalent Proportions of Cations in Hawaiian Streams Compared with Other Natural Waters

	Mean River ^a	Water From Igneous Rocks ^a	Mean, Hawaiian Streams ^b
Calcium	63.5	48.3	31.0
Magnesium	17.4	14.2	20.4
Sodium	15.7	30.6	43.7
Potassium	3.4	6.9	4.9

^aFrom Hutchinson 1957, p. 555.

^bFrom USGS 1976; see also Table 14.

EFFECT OF ALTERED CHANNELS ON WATER TEMPERATURE

The temperature regime of a shallow spring-fed stream such as those in Hawaii is affected by several factors: season, weather, time of day, elevation, length of channel, character of riparian vegetation, and others.

Manoa Stream is one example of an altered stream in which lined channels, revetments, cleared/realigned, as well as unaltered sections are found. Located in Manoa Valley, Oahu, it drains 27 km² and has a total of 34 km channel, 8 km of which has been altered. Water temperature was taken in altered and unaltered sections of the stream at various times of the year (1975-1976); results are summarized in Table 16. Allowing for a warming of 1.4° C (line 7 minus line 6) as water flows from mid-elevation to near the

mouth, an average of more than 7° C (line 1 minus line 4) could be attributed to the warming effect of a lined channel, 4° C (line 2 minus line 5) for a revetment, and about 2° C (line 3 minus line 5) for a cleared and/or realigned section. Hathaway (personal communication), who is studying the effect of a lined channel on water temperature at Maunawili Stream as part of this channelization study, attributes only 2.5° C (range 0.8 - 4.4) to it but finds the warming effect of Waiahole Stream as it flows from 45 m to 1 m elevation to be 2.0° C (range 0.8 - 3.2). A more definitive study of this parameter will be available in the terminal report for Part C (FWS/OBS-78/18) of this contract study.

Table 16. Water Temperatures in Altered and Unaltered Sections of Manoa Stream^a and Unaltered Waiahole Stream^b

Type of Channel, Elevation	Mean Temperature (Range) °C
1. Lined channel, Manoa (Palolo tributary), 3 m	31.3 (26.5-35.0)
2. Revetment, Manoa, 1 m	26.6 (22.5-30.0)
3. Cleared/Realigned, Manoa, 12 m	24.4 (22.4-25.0)
4. Unaltered, Manoa (Pukele trib.), 110 m	22.1 (20.6-22.8)
5. Unaltered, Manoa (Waiakeakua trib.), 105 m	20.8 (20.5-21.3)
6. Unaltered, Waiahole ^c , 45 m	21.2 (20.2-22.1)
7. Unaltered, Waiahole ^c , 1 m	22.6 (22.0-23.8)

^aManoa Stream: drainage area = 27 km², mean flow = 0.25 m³/s (USGS 1977).

^bWaiahole Stream: drainage area = 10 km², mean flow = 0.24 m³/s (USGS 1968).

^cNorton (1977).

ECOLOGICAL QUALITY STATUS

An attempt was made to identify the ecological quality of all perennial streams. Quality status assignment was made on the basis of field observations whenever possible; ecological quality of streams not visited was estimated from the character of the locality wherein they occur. Assignment of ecological quality was done according to the status-use categories listed in the proposed State water quality standards (Hawaii Department of Health 1977) as follows:

- (I) Pristine-preservation are streams of high quality;
- (II) Limited consumptive are streams of moderate to high quality where use is controlled;
- (III) Exploitive-consumptive are streams of moderate to low quality and well exploited; and
- (IV) Construct-alter are streams of low quality. (see also Appendix A.)

Including both perennial and possibly perennial streams on an island-wide basis, Molokai has the largest percentage of high quality streams, with 81% of its streams belonging to the pristine-preservation status (Category I), 16% under limited consumptive (Category II), and only 3% (one stream) under exploitive-consumptive (Category III). There are no streams on Molokai that are classified as construct-alter (Category IV).

Maui has the next highest percentage of high quality streams, with 34% under Category I, 46% under Category II, 20% under Category III, and none under Category IV. Hawaii comes after Maui since 21% of its streams are of high quality (Category I), 74% under Category II, 5% under Category III, and none under Category IV.

Kauai has all four categories of ecological quality. Twenty percent of its streams are of high quality (Category I), 37% are under Category II, 39% under Category III, and 4% under Category IV. Oahu has the dubious distinction of having the poorest quality streams. There are no longer any streams which could be classified as pristine-preservation (Category I). The best streams (43%) are of limited consumptive quality (Category II). In addition, 44% of its streams are classified as exploitive-consumptive (Category III), and 13% (the highest statewide) are of the lowest quality (Category IV).

On a statewide basis, 51% of all perennial streams come under limited consumptive (Category II), 27% under pristine-preservation status (Category I), 20 % under exploitive-consumptive (Category III), and 2% under construct-alter (Category IV).

SUMMARY AND CONCLUSIONS

Although streams are Hawaii's most significant class of inland water (in area and numbers), no systematic statewide listing or description of them exists. Many are known to have been channelized, but the extent of channel alteration has not been documented. The effect of these alterations on the physicochemical features of the streams and the nature of the major fauna associated with inland water have not been explored. The purpose of this study was to compile a comprehensive index of perennial streams that is detailed with respect to locations, physical characteristics, and changes in aquatic ecology that have resulted.

STREAM SURVEY

Perennial Streams

At least 366 perennial streams have been recognized in the five major islands of the State. Fifty-nine percent of these streams are continuous, with Kauai having the highest percentage of its streams continuous and Molokai the lowest.

Altered Streams

Of the 366 streams identified, 15% have been channelized. More than half of these altered streams (8% of all perennial Hawaiian streams) are found in Oahu, followed by Kauai, Hawaii, Maui, and Molokai in decreasing order.

Types and "Abundances" of Alterations

Six types of channel modifications have been identified: lined channel, channel realigned and/or vegetation removed, elevated culvert, revetment, blocked or filled-in channel, and extended culvert. A total length of 151 km of these modifications have been identified statewide. The comparative "abundances" of these are: lined channel, 40%; realigned/cleared, 28%; revetment, 24%; blocked channel, 5%; elevated culvert, 3%; and extended culvert <1%. Eighty-nine percent of the total length of lined channel is located on Oahu.

ASSOCIATED MACROFAUNA

Electrofishing

Extent of the inventory necessitated a selective restriction of the faunal taxa surveyed. Collections were made primarily by electrofishing, an effective and adaptable method of stream sampling. This limited the survey to susceptible animals - fishes and decapod crustaceans - which are also the largest and most representative stream species exclusive of headwater areas.

Macrofaunal Inventory

Twenty-five species of fish and decapod crustaceans were collected statewide. Twenty-three of these species are found on Oahu, 17 on Kauai, 13 on Maui, 12 on Hawaii, and 9 on Molokai. Seventeen of these species are exotic. The proportion of native species relative to the total number is highest in Molokai (89%), followed by Hawaii (67%), Maui (62%), Kauai (47%), and Oahu (30%). This survey substantiated the absence of the endemic goby, Lentipes concolor, on Oahu--one of two islands from which it was described originally. The introduced guppy, Poecilia reticulata, was the most widely distributed and abundant species.

Macrofauna in Altered and Unaltered Streams

Both in numbers and biomass, native species are dominant in most unaltered streams, while exotic species are dominant in altered streams. No native species were collected from lined channels.

Indicator Species

Three endemic Hawaiian gobies (o'opu alamoo, Lentipes concolor; o'opu nopili, Sicydium stimpsoni; and o'opu nakea, Awaous stamineus) require clean fresh water in considerable volume flowing through comparatively unaltered stream channels. The population density of Lentipes concolor is now low where present at all. Both Awaous stamineus and Sicydium stimpsoni are present in comparatively high population density in most unaltered streams. However, Awaous stamineus is a food fish (there is a minor nakea fishery in Kauai) subject to fishing pressures in addition to pressures due to stream degradation. Sicydium stimpsoni, which is found in all five major islands (see Tables 3, 7, 8, 10, and 12) is not subject to harvesting. The decline in population density, or in extreme cases, the disappearance of the o'opu nopili from a stream, is a good indication of serious stream degradation.

PHYSICOCHEMICAL CHARACTERS

Discharge

The largest among Hawaiian streams is Wailuku on the island of Hawaii. On an island-wide basis, Hawaii and Kauai have the highest yearly mean discharge, followed by Maui, Oahu, and Molokai in decreasing order.

Composition of Stream Water

Oahu streams carry the highest total dissolved solids, followed by Maui, Kauai, Molokai, and Hawaii in decreasing order. Conductivity follows the same general pattern. There appears to be no significant difference in pH values on an island-wide basis. The major cation contents of Hawaiian stream water are nearer those of water from igneous rocks than of major rivers of the world.

Effects of Alterations on Water Temperature

Pending results of an on-going study, it can be said that the warming effect of a lined channel is about twice that of a revetment and about four times that of a clearing/realignment. Elevated temperatures appear to be related to shallowness, loss of vegetative cover, channel substrate, and strong insolation.

STREAM QUALITIES

Of the 366 perennial streams in the State, only 14% may be physically pristine. On an island basis, the order is as follows: Molokai> Kauai> Hawaii> Maui> Oahu. Oahu no longer has any physically pristine streams.

The presence of exotic macrofauna in all streams sampled indicates that there are apparently no longer any biologically pristine streams in the State, confirming earlier findings of Maciolek (1975, MS).

Only about 27% of the State's perennial streams may be of high ecological quality. On an island-wide basis, Molokai has the largest percentage of its streams belonging to the pristine-preservation category, followed by Maui, Hawaii, Kauai, and Oahu in decreasing order. Oahu has no stream which can be classified under pristine-preservation.

Fifty-three percent of the State's perennial streams have some form of water diversion. Hawaii, Maui, and Oahu each has about 60% of its streams diverted; Kauai has 46% and Molokai 14%.

STREAM ALTERATION, A CONTINUING PROCESS

This inventory of altered streams should not be considered final. Since this study was begun, alterations were started and completed in Waimanalo and Kahaluu Streams on Oahu, a dam is being constructed on a Kaneohe Stream tributary, and alteration is going on in Iao Stream on Maui. Plans are being processed for additional channel alterations in Kawa and Heeia Streams on Oahu.

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Appendix A. Comprehensive List of Perennial Hawaiian Streams and Tributaries
as Named on USGS Quadrangle Maps (Undesignated Streams Named
After Land Divisions or Adjacent Features).

Streams are listed alphabetically by island and located by grid coordinates determined from USGS topographic maps. Herein, a stream is defined as a single discharge to the ocean regardless of the number and length of tributaries.

Assignment of ecological quality was done according to the status-use categories listed in the proposed State water quality standards (Department of Health 1977) as described below. Quality status assignment was made on the basis of field observations wherever possible; ecological quality of streams not visited was estimated from the character of the locality in which they occur. In most cases, the ecological status of streams listed here agrees with that of the State Department of Health.

LEGEND FOR APPENDIX

Stream Name and Location

1. First word is stream name: second word is topographic quadrangle map, i.e., Aamakao (Stream): Hawi (second word of quadrangle sheet name, if any, is omitted to save space, e.g., Schofield = Schofield Barracks).
2. Grid coordinates indicate stream mouth location; latitude North, longitude West.

Ecological Quality Status

First Index.

- (I) Pristine-Preservation. High environmental and biological quality: use range from no consumptive, degrading or modifying to special exploitive (but non-degrading). For purposes of this report, subcategories IA and IB proposed by the Department of Health (1977) are ignored.
- (II) Limited Consumptive. Moderate to high quality water or natural values: controlled use to prevent excessive modification.
- (III) Exploitive-Consumptive. Moderate to low natural and/or water quality (well exploited, modified or degraded): used for water related recreational activities.
- (IV) Construct-Alter. Low environmental and biological quality: may be restricted to public for health or safety reasons.

Stream Characteristics

Second Index.

A = Channelized or stream channel altered.

N = Not channelized or stream channel not altered.

Third Index.

C = Continuous: naturally flowing to the sea year-round.

I = Interrupted: intermittent flow in a portion of channel, discharges into the sea during wet season.

Fourth Index.

DI = Water diverted (numeral indicates number of diversions in stream system).

U = No diversion(s).

Fifth Index.

Arabic numeral(s) indicates number of roadways of all kinds crossing all stream channels.

Example.

105.0^a Wailoa R.^b: Hilo^c

(III)^d A^e I^f D2^g 22^h

19°43'36", 155°04'25"ⁱ

105.1 Alenaio^j

^aStream number.

^bStream name.

^cTopographic map name.

^dEcological quality category.

^eAltered stream channel.

^fInterrupted stream.

^gDiverted at two sites.

^hNumber of roadway crossings.

ⁱStream mouth location.

^jStream tributary.

1. Hawaii Island.

001.0 Aamakao: Hawi
(II) N C D6 15
20°13'56", 155°45'17"

002.0 Aamanu: Kukaiau
(I) N C U 2
20°03'11", 155°21'25"

003.0 Ahole: Papaaloa
(II) N C U 3
20°57'10", 155°10'57"

004.0 Alakahi: Honomu
(II) N C D1 5
19°48'37", 155°05'41"

005.0 Alia: Honomu
(II) N C D2 15
19°51'16", 155°05'11"

006.0 Alilipali: Honokaa
(II) N I D1 5
20°04'17", 155°23'58"

007.0 Hakalau: Papaaloa
(II) N C D1 19
19°54'11", 155°07'54"

007.1 Hakalau segment
007.2 Kamaee
007.3 Waawaa

008.0 Halawa: Hawi
(II) N I D3 8
20°14'21", 155°45'42"

009.0 Hanaula: Hawi
(II) N I D3 9
20°15'04", 155°47'58"

010.0 Hanawi: Honomu
(II) N C D2 10
19°48'30", 155°05'37"

011.0 Hapahapai: Hawi
(II) N I D3 8
20°15'02", 155°47'33"

012.0 Heeka: Honomu
(II) N C D1 5
19°48'06", 155°05'22"

013.0 Honokane Iki: Honokane
(II) N C D2 0
20°11'45", 155°43'08"

014.0 Honokane Nui: Honokane
(II) N C D7 0
20°12'00", 155°43'14"

015.0 Honokea: Honokane
(II) N C D3 0
20°11'21", 155°42'08"

016.0 Honolii: Honomu
(II) N C D1 15
19°45'35", 155°05'37"

016.1 Honolii segment
016.2 Kaiwiki
016.3 Pohakupaa

017.0 Honomu: Honomu
(II) N C U 5
19°52'22", 155°06'28"

018.0 Honopue: Honokane
(II) N C D2 0
20°10'52", 155°41'28"

019.0 Kaaheiki: Papaaloa
(II) N C U 4
20° 56' 38", 155°10'21"

020.0 Kaala: Kukaiau
(I) N I U 1
20°02'06", 155°19'08"

021.0 Kaalau: Papaaloa
(II) N I D1 8
20°58'26", 155°12'35"

021.1 Kaalau segment
021.2 Pahale

022.0 Kaapoko: Honomu
(II) N C D1 2
19°47'36", 155°05'34"

- 023.0 Kaawalii: Kukaiau
(I) N I U 2
20°00'31", 155°15'53"
- 024.0 Kahaupu: Honokaa
(II) N I D3 3
20°05'31", 155°26'20"
- 025.0 Kahawailiili: Honokaa
(II) N I D2 5
20°05'29", 155°26'08"
- 026.0 Kahoopuu: Kukuihaele
(I) N C U 0
20°08'21", 155°36'53"
- 027.0 Kahuku: Papaaloa
(II) N C U 2
20°56'11", 155°09'47"
- 028.0 Kaieie: Honomu
(II) N C D3 10
19°47'52", 155°05'34"
- 029.0 Kailikaula: Honokane
(II) N C D1 0
20°11'10", 155°41'43"
- 030.0 Kaimu: Honokane
(I) N C U 0
20°09'35", 155°38'59"
- 031.0 Kaiwiki: Kukaiau
(II) N C U 3
20°01'29", 155°17'39"
- 032.0 Kaiwilahilahi: Papaaloa
(II) N C D1 3
20°58'49", 155°13'20"
- 033.0 Kalaoa: Honomu
(II) N C D1 5
19°48'26", 155°05'34"
- 034.0 Kalopa: Honokaa
(II) N I D1 2
20°04'28", 155°24'46"
- 035.0 Kaohaoha: Kukaiau
(II) N C U 4
20°00'48", 155°16'11"
- 036.0 Kapehu: Papaaloa
(II) N C D1 5
20°58'14", 155°12'21"
- 037.0 Kapehu: Honomu
(II) N C D1 20
19°52'05", 155°05'53"
- 038.0 Kapue: Honomu
(II) N C D1 21
19°46'52", 155°05'26"
- 039.0 Kaula: Kukaiau
(II) N C D1 5
20°01'21", 155°17'18"
- 040.0 Kaumoali: Honokaa
(II) N I D1 4
20°04'09", 155°23'38"
- 041.0 Kawaikalia: Kukuihaele
(II) N I D2 3
20°07'06", 155°31'20"
- 042.0 Kawainui: Honomu
(II) N C U 10
19°49'24", 155°05'30"
- 043.0 Keahua: Honokaa
(II) N C D2 6
20°05'07", 155°25'14"
- 044.0 Kealakaha: Kukaiau
(I) N I U 2
20°01'55", 155°18'43"
- 045.0 Kihalani: Papaaloa
(II) N C D1 2
20°58'59"; 155°13'30"
- 046.0 Kilau: Papaaloa
(I) N C U 2
20°59'35"; 155°14'34"
- 047.0 Koholalele: Kukaiau
(II) N I D1 10
20°03'06", 155°03'06"
- 047.1 Kawaili
047.2 Koholalele segment

- 048.0 Kolealiilii: Honokane
(II) N C D2 0
20°10'50", 155°40'57"
- 048.1 Kolealiilii segment
048.2 Oniu
- 049.0 Kolekole: Honomu
(II) N C U 10
19°53'10", 155°07'17"
- 049.1 Kaahakini
049.2 Kalakoo
049.3 Kolekole segment
- 050.0 Kukaiau: Kukaiau
(II) N I U 5
20°02'30", 155°20'05"
- 051.0 Kukui: Honokane
(I) N C U 0
20°10'22", 155°39'57"
- 052.0 Kukuilamalamahii: Honokaa
(II) N C D1 5
20°04'24", 155°24'03"
- 053.0 Kumakua: Hawi
(II) N C D4 9
20°15'43", 155°49'11"
- 054.0 Kupapaulua: Kakaiau
(I) N I U 5
20°01'29", 155°17'46"
- 055.0 Kuwaikahi: Papaaloa
(II) N C D1 4
20°59'10", 155°13'53"
- 056.0 Laimi: Honomu
(II) N C U 11
19°52'16", 155°06'04"
- 057.0 Laupahoehoe: Papaaloa
(I) N I U 6
20°59'48", 155°14'39"
- 057.1 Kapili
057.2 Laupahoehoe segment
- 058.0 Maili: Honomu
(II) N C D1 5
19°45'35", 155°05'42"
- 059.0 Makahanaloa: Honomu
(II) N C D1 7
19°50'58", 155°05'12"
- 060.0 Makea: Honomu
(II) N C D2 12
19°51'25", 155°05'26"
- 061.0 Malanahae: Kukuihaele
(II) N I D2 3
20°06'54", 155°31'00"
- 062.0 Manoloa: Papaaloa
(I) N C U 2
20°56'51", 155°10'37"
- 063.0 Manowaiopae: Papaaloa
(II) N C D1 2
20°59'16", 155°14'00"
- 064.0 Manuwaikaalio: Kukuihaele
(I) N C U 0
20°08'41", 155°37'25"
- 065.0 Maulua: Papaaloa
(I) N I U 1
20°57'29", 155°11'49"
- 065.1 Makahiloa
065.2 Maulua segment
- 066.0 Moanalulu: Papaaloa
(II) N C D1 6
20°58'41", 155°12'58"
- 066.1 Ahoa
066.2 Haakoa
066.3 Moanalulu segment
- 067.0 Nakooko: Honokane
(II) N C D1 0
20°10'38", 155°40'33"
- 068.0 Naluea: Kukuihaele
(I) N C U 0
20°08'24", 155°37'01"

069.0 Nanue: Papaaloa
 (II) N C U 3
 20°55'53", 155°09'30"

069.1 Kaahina

069.2 Nanue segment

069.3 Painiu

070.0 Nienie: Honokaa
 (II) N I D4 6
 20°06'17", 155°28'26"

071.0 Ninole: Papaaloa
 (II) N C U 3
 20°56'42", 155°10'25"

072.0 Niulii: Honokane
 (II) N C D3 9
 20°13'33", 155°44'55"

073.0 Ohiahuea: Honokane
 (II) N C D1 0
 20°10'39", 155°40'39"

074.0 Onomea: Honomu
 (II) N C D2 9
 19°48'43", 155°05'42"

075.0 Opea: Papaaloa
 (II) N C U 7
 20°55'39", 155°09'14"

076.0 Paauilo: Kukaiau
 (II) N I U 3
 20°03'12", 155°21'30"

077.0 Pae: Honokane
 (I) N C U 0
 20°09'27", 155°38'39"

078.0 Paeohe: Papaaloa
 (I) N C D2 5
 20°57'29", 155°11'53"

079.0 Paheehee: Honomu
 (II) N C U 14
 19°52'46", 155°06'47"

080.0 Pahoehoe: Honomu
 (II) N C D1 4
 19°46'36", 155°05'32"

080.1 Pahoehoe segment

080.2 Waikoana

081.0 Pali Akamoa: Hawi
 (II) N I D1 4
 20°14'42", 155°46'46"

082.0 Paopao: Honokane
 (I) N C U 0
 20°10'09", 155°39'39"

083.0 Papaikou: Honomu
 (II) N C D1 6
 19°47'12", 155°05'20"

084.0 Papuaa: Honokaa
 (II) A C D1 8
 20°06'12", 155°28'12"

085.0 Paukaa: Honomu
 (II) N C D2 5
 19°46'16", 155°05'37"

086.0 Peleau: Papaaloa
 (II) N C U 4
 20°55'14", 155°08'39"

087.0 Pohakupuka: Papaaloa
 (II) N C U 7
 20°57'22", 155°11'16"

087.1 Huliilii

087.2 Kaoheanu

087.3 Pohakupuka segment

088.0 Pololu: Honokane
 (II) N C D5 0
 20°12'26", 155°44'01"

088.1 Kapoloa

088.2 Pololu segment

088.3 Waiakalae

089.0 Poupou: Papaaloa
 (I) N C U 2
 20°56'53", 155°10'41"

- 090.0 Pukihae: Hilo
(II) A C D1 7
19°44'09", 155°05'30"
- 091.0 Pukoa: Honokane
(I) N C U 0
20°08'45", 155°37'33"
- 092.0 Punalulu: Honokane
(I) N C U 0
20°09'55", 155°39'06"
- 093.0 Puuokalepa: Honomu
(II) N C D1 10
19°47'45", 155°05'33"
- 093.1 Kumuwane
093.2 Puuokalepa segment
- 094.0 Umauma: Papaaloa
(II) N C D1 12
20°54'37", 155°08'17"
- 094.1 Hanapueo
094.2 Umauma segment
- 095.0 Waiaalala: Honokane
(I) N C U 0
20°10'05", 155°39'29"
- 096.0 Waiaama: Honomu
(II) N C U 3
19°49'45", 155°05'22"
- 097.0 Waiapuka: Honokane
(II) N C D2 0
21°10'35", 155°40'21"
- 097.1 Kamoloumi
097.2 Waiapuka segment
- 098.0 Waiehu: Papaaloa
(II) N C U 4
20°56'06", 155°09'38"
- 099.0 Waikaalulu: Honokaa
(II) N I D1 5
20°04'46", 155°24'28"
- 100.0 Waikaloa: Honokane
(II) N C D1 0
21°10'31", 155°40'14"
- 101.0 Waikama: Honokane
(II) N C D1 3
20°13'17", 155°44'11"
- 102.0 Waikaumalo: Papaaloa
(II) N C U 3
20°56'14", 155°09'48"
- 103.0 Waikoloa: Kukuihaele
(II) N I D3 7
20°07'30", 155°32'32"
- 104.0 Waikolu: Papaaloa
(II) N C U 4
20°56'32", 155°10'14"
- 105.0 Wailoa R.: Hilo
(III) A I D2 22
19°43'36", 155°04'25"
- 105.1 Alenaio
105.2 Kaluiiki
105.3 Waiakea
105.4 Wailoa R. segment
105.5 Waipahoe
- 106.0 Wailoa: Kukuihaele
(II) N C D7 1
20°07'21", 155°35'28"
- 106.1 Alakahi
106.2 Hiilawe
106.3 Kawaiki
106.4 Kawainui
106.5 Koiawe
106.6 Nanaue
106.7 Wailoa segment
106.8 Waima
106.9 Waipio
- 107.0 Wailuku R.: Hilo
(II) N C D2 39
19°43'55", 155°05'24"
- 107.1 Aale
107.2 Awehi

107.3 Hookelekele
 107.4 Kahoama
 107.5 Kalohewahewa
 107.6 Kapehu
 107.7 Kipi
 107.8 Laualu
 107.9 Mokupau
 107.10 Nakakauila
 107.11 Pakaluahine
 107.12 Waiau
 107.13 Wailuku R. segment

108.0 Waimaauou: Honomu
 (II) N C U 12
 19°50'00", 155°05'12"

109.0 Waimaile: Honokane
 (I) N C U 0
 20°10'29", 155°49'04"

110.0 Waimanu: Honokane
 (I) N C U 0
 20°08'45", 155°38'14"

110.1 Kakaauki
 110.2 Waihilau
 110.3 Waiilikahi
 110.4 Waimanu segment

111.0 Wainaia: Hawi
 (II) N I D6 7
 20°14'43", 155°46'42"

112.0 Waipahi: Honokane
 (II) N C D1 0
 20°11'37", 155°42'37"

113.0 Waipahoehoe: Kukuihaele
 (I) N C U 0
 20°08'02", 155°36'22"

114.0 Waipunahina: Honokaa
 (II) N I D3 15
 20°03'41", 155°22'29"

115.0 Waipunahoe: Kukuihaele
 (II) N I D4 10
 20°07'47", 155°33'07"

116.0 Waipunalei: Keanakolu
 (II) N C U 4
 20°00'00", 155°15'09"

117.0 Waiulili: Kukuihaele
 (II) N C D3 7
 20°07'26", 155°34'47"

Possible Interrupted Streams:

118.0 Haloa: Kamuela
 (III) N I U 2
 20°01'50", 155°38'21"

119.0 Hilea: Naalehu
 (III) N I U 6
 19°07'00", 155°31'41"

120.0 Kiilae: Honaunau
 (II) N I U 1
 19°24'48", 155°54'27"

121.0 Lamimaumau: Kamuela
 (III) A I D1 13
 20°00'56", 155°40'25"

122.0 Waiaha: Kailua
 (III) N I D2 4
 19°37'46", 155°58'26"

123.0 Waiulaula: Kawaihae
 (III) N I D2 15
 20°01'01", 155°49'21"

123.1 Keanuimano
 123.2 Kohakohau
 123.3 Waikoloa
 123.4 Waiulaula segment

2. Maui Island.

001.0 Alaaula: Kipahulu
(I) N C U 1
20°41'14", 156°01'15"

002.0 Alelele: Kaupo
(I) N C U 1
20°39'04", 156°05'13"

003.0 East Wailuaiki: Keanae
(II) N C D1 1
20°50'21", 156°07'36"

004.0 Hahalawe: Kipahulu
(I) N C U 2
20°40'24", 156°02'30"

004.1 Hahalawe segment
004.2 Maluhianaiwi

005.0 Haipuaena: Keanae
(II) N C D3 1
20°52'37", 156°10'28"

006.0 Hanawana: Haiku
(II) N C D1 0
20°54'21", 156°12'47"

007.0 Hanawi: Nahiku
(II) N C D3 1
20°49'41", 156°06'13"

008.0 Hanehoi: Nahiku
(II) N C D5 3
20°54'39", 156°13'01"

008.1 Hanehoi segment
008.2 Huelo

009.0 Heleleikeoha: Hana
(I) N I U 1
20°48'38", 156°03'36"

010.0 Hoalua: Haiku
(II) N C D3 1
20°54'25", 156°12'59"

011.0 Honokahua: Honolulu
(II) N C D2 2
21°00'29", 156°39'07"

012.0 Honokowai: Lahaina
(III) A I D5 6
20°57'13", 156°41'33"

012.1 Amalu
012.2 Honokowai segment
012.3 Kapaloa

013.0 Honokohau: Honolulu
(III) N C D2 2
21°01'29", 156°36'43"

014.0 Honolewa: Kipahulu
(I) N C U 1
20°41'01", 156°01'46"

015.0 Honolulu: Honolulu
(III) N C D2 3
21°01'00", 156°38'29"

016.0 Honomaele: Hana
(I) N I U 4
20°48'30", 156°02'19"

017.0 Honomanu: Keanae
(II) N C D3 1
20°51'56", 156°10'12"

17.1 Honomanu segment
17.2 Uluini

018.0 Honopou: Haiku
(II) N C D6 2
20°56'20", 156°14'29"

018.1 Honopou segment
018.2 Puniawa

019.0 Hoolawa: Haiku
(II) N C D5 1
20°56'00", 156°14'30"

019.1 Hoolawa segment
019.2 Hoolawaliilii
019.3 Hoolawanui

- 020.0 Iao: Wailuku
(II) A C D9 6
20°54'43", 156°29'07"
- 020.1 Ae
020.2 Iao segment
020.3 Kinihapai
020.4 Nakalaloa
020.5 Poohahoahoa
- 021.0 Kaaiea: Keanae
(II) N C D4 1
20°53'17", 156°11'32"
- 022.0 Kaapahu: Kipahulu
(I) N C U 1
20°39'15", 156°04'55"
- 023.0 Kahakuloa: Kahakuloa
(II) N C U 1
21°00'05", 156°33'07"
- 024.0 Kahana: Honolulu
(II) N I D3 7
20°58'50", 156°40'50"
- 024.1 Kahana segment
024.2 Mailepai
- 025.0 Kahoma: Lahaina
(III) A C D6 3
20°53'20", 156°41'21"
- 025.1 Halona
025.2 Kahoma segment
025.3 Kanaha
- 026.0 Kailua: Keanae
(II) N C D4 1
20°54'07", 156°12'27"
- 026.1 Kailua segment
026.2 Oanui
- 027.0 Kakipi: Haiku
(II) N C D17 4
20°56'10", 156°15'32"
- 027.1 Kakipi segment
027.2 Kapalaalaea
027.3 Kaulu
- 027.4 Koale
027.5 Makaa
027.6 Papalua
027.7 Piiloi
027.8 Waihee
- 028.0 Kakiweka: Kipahulu
(I) N C U 1
20°40'26", 156°02'22"
- 029.0 Kapaula: Nahiku
(II) N C D1 1
20°49'25", 156°06'34"
- 030.0 Kapia: Hana
(I) N I U 1
20°42'59", 155°59'30"
- 031.0 Kauaula: Lahaina
(III) A C D7 5
20°51'42", 156°40'18"
- 032.0 Kaupakulua: Haiku
(II) N I D8 4
20°56'41", 156°18'06"
- 033.0 Kawaipapa: Hana
(II) N I D2 1
20°45'51", 155°59'22"
- 034.0 Kawakoe: Hana
(I) N I U 2
20°48'34", 156°03'13"
- 034.1 Kawakoe segment
034.2 Mokulehua
- 035.0 Keeaiki: Hana
(I) N I U 1
20°49'05", 156°04'03"
- 036.0 Kolea: Keanae
(II) N C D1 1
20°53'06", 156°11'11"
- 037.0 Kopiliula: Keanae
(II) N C D2 2
20°50'10", 156°07'16"
- 037.1 Kopiliula segment
037.2 Puakaa

- 038.0 Koukouai: Kipahulu
(III) N I U 1
20°39'07", 156°03'45"
- 039.0 Kuhiwa: Nahiku
(I) N C U 1
20°49'40", 156°05'08"
- 040.0 Kuiaha: Haiku
(III) N I D13 6
20°56'45", 156°18'49"
- 040.1 Kuiaha segment
040.2 Ohia
- 041.0 Kukuiula: Kipahulu
(I) N C U 1
20°39'12", 156°04'42"
- 042.0 Laniupoko: Lahaina
(III) N C D1 2
20°50'12", 156°38'53"
- 043.0 Leleka: Kaupo
(I) N C U 1
22°39'14", 156°05'00"
- 044.0 Makamakaole: Kahakuloa
(II) N C D1 1
20°58'05", 156°31'41"
- 045.0 Makapipi: Nahiku
(II) N C D1 2
20°49'49", 156°05'49"
- 046.0 Maliko: Paia
(II) N I D6 8
20°56'20", 156°20'32"
- 047.0 Manawaiiao: Haiku
(II) N I D2 2
20°56'46", 156°17'50"
- 048.0 Manawaikae: Hana
(I) N I U 1
20°49'24", 156°04'37"
- 049.0 Manawainui: Kaupo
(II) N I D1 1
20°38'17", 156°06'59"
- 049.1 Healani
049.2 Manawainui segment
- 050.0 Moomoonui: Hana
(I) N I U 1
20°44'39", 155°59'07"
- 051.0 Nailiilihaele: Keanae
(II) N C D2 1
20°54'06", 156°12'26"
- 052.0 Nuaailua: Keanae
(III) N C D1 1
20°51'46", 156°09'40"
- 053.0 Nuanuaaloa: Kaupo
(I) N I U 2
22°38'43", 156°06'08"
- 054.0 Olowalu: Olowalu
(III) N C D4 3
20°48'58", 156°37'48"
- 055.0 Oopuola: Keanae
(III) N C D6 2
20°53'31", 156°11'55"
- 055.1 Makanali
055.2 Oopuola segment
- 056.0 Paakea: Nahiku
(II) N C D1 1
20°49'50", 156°07'04"
- 057.0 Palikea: Kipahulu
(II) N C U 1
20°39'59", 156°02'38"
- 057.1 Palikea segment
057.2 Pipiwai
- 058.0 Papaahawahawa: Kipahulu
(I) N C U 1
20°41'21", 156°00'41"
- 059.0 Piinau: Keanae
(II) N C D3 3
20°51'50", 156°08'50"
- 059.1 Kuo
059.2 Palauhulu

059.3	Piinau segment	068.0	Waihole: Nahiku
059.4	Pokakaekane	(I)	N I U 2
			20°49'26", 156°04'42"
060.0	Punalau: Keanae	069.0	Waikamoi: Keanae
(III)	N C D3 1	(III)	N C D4 0
	20°51'55", 156°10'12"		20°52'56", 156°11'00"
060.1	Kolea	069.1	Alo
060.2	Punalau segment	069.2	Waikamoi segment
061.0	Puohokamoa: Keanae	070.0	Waikapu: Maalaea
(II)	N C D5 1	(II)	A C D9 9
	20°52'35", 156°10'38"		20°47'40", 156°28'51"
062.0	Uaoo: Haiku	071.0	Wailua: Kipahulu
(II)	N I D3 2	(I)	N C U 2
	20°56'14", 156°16'29"		20°41'02", 156°01'42"
063.0	Ukumehame: Olowalu	072.0	Waiohonu: Kipahulu
(II)	N C D2 3	(I)	N I U 1
	20°48'09", 156°33'44"		20°42'26", 155°59'51"
063.1	Hokuula	073.0	Waiohue: Nahiku
063.2	Ukumehame segment	(II)	N C D1 1
064.0	Wahikuli: Lahaina		20°49'51", 156°07'05"
(III)	A I D7 8	074.0	Waiokamilo: Keanae
	20°54'50", 156°41'34"	(III)	N C D1 1
064.1	Hahakea		20°51'06", 156°07'52"
064.2	Wahikuli segment	075.0	Waioni: Hana
065.0	Waiehu: Wailuku	(I)	N I U 1
(II)	A C D5 8		20°48'55", 156°03'58"
	20°55'17", 156°29'40"	076.0	Waipio: Haiku
065.1	North Waiehu	(III)	N C D3 2
065.2	South Waiehu		20°55'04", 156°13'48"
065.3	Waiehu segment	077.0	West Wailuaiki: Keanae
066.0	Waieli: Kipahulu	(II)	N C D1 1
(III)	N C U 1		20°50'25", 156°07'42"
	20°40'37", 156°02'12"	078.0	West Wailuanui: Keanae
067.0	Waihee R.: Wailuku	(II)	N C D2 1
(II)	N C D5 5		20°50'37", 156°07'51"
	20°57'05", 156°30'43"	078.1	East Wailuanui
067.1	Huluhulupueo	078.2	West Wailuanui
067.2	Mananole		segment
067.3	Waihee segment		

Possible Interrupted Streams.

079.0 Haneoo: Hana
 (I) N I U 1
 20°43'52", 155°59'14"

080.0 Holoinawawae: Hana
 (I) N I U 1
 20°45'50", 155°59'39"

081.0 Honanana: Kahakuloa
 (I) N I U 1
 21°00'56", 156°34'09"

082.0 Kahawaihapapa: Hana
 (I) N I U 1
 20°49'18", 156°04'24"

083.0 Kalena: Kipahulu
 (III) N I U 11
 20°39'08", 156°03'41"

084.0 Kalepa: Kaupo
 (I) N I U 1
 20°39'08", 156°05'20"

085.0 Kealii: Haiku
 (II) N I D1 0
 20°56'24", 156°16'09"

086.0 Lanikele: Hana
 (I) N I U 1
 20°48'50", 156°03'45"

087.0 Maalo: Kaupo
 (I) N I U 1
 20°38'37", 156°06'43"

088.0 Ohia: Keanae
 (I) N I U 0
 20°51'40", 156°08'30"

089.0 Opelu: Kipahulu
 (I) N I U 1
 20°39'10", 156°04'36"

090.0 Poelua: Kahakuloa
 (I) N I U 1
 21°01'11", 156°34'57"

091.0 Pohakea: Maalaea
 (II) N I D3 6
 20°47'59", 156°29'48"

092.0 Puaaluu: Kipahulu
 (I) N I U 1
 20°40'11", 156°02'37"

093.0 Puehu: Keanae
 (II) N I D1 1
 20°53'51", 156°11'55"

094.0 Wahinepee: Keanae
 (I) N I U 1
 20°52'50", 156°10'53"

095.0 Waiaaka: Nahiku
 (III) N I D1 1
 20°49'40", 156°06'57"

096.0 Waiolai: Kahakuloa
 (II) N I D1 2
 20°58'24", 156°31'45"

3. Oahu Island.

- 001.0 Aiea: Waipahu
(IV) A I D1 6
21°22'16", 156°56'15"
- 002.0 Anahulu R.: Haleiwa
(II) N C D10 13
21°35'50", 156°06'31"
- 002.1 Anahulu R. segment
002.2 Kawaiiki
002.3 Kawainui
- 003.0 Hakipuu: Kahana
(II) N I U 2
21°30'33", 157°51'16"
- 004.0 Halawa: Puuloa
(III) A C U 10
21°22'08", 156°56'25"
- 004.1 Halawa segment
004.2 North Halawa
004.3 South Halawa
- 005.0 Heeia: Kaneohe
(II) A C D1 9
21°26'23", 157°48'46"
- 006.0 Honouliuli: Ewa
(III) N I D10 54
21°21'57", 158°01'30"
- 007.0 Kaaawa: Kahana
(II) N I U 4
21°32'55", 157°50'49"
- 008.0 Kaalaea: Kaneohe
(III) A C U 3
21°28'13", 157°50'43"
- 009.0 Kahaluu: Kaneohe
(II) A C D2 14
21°27'51", 157°50'30"
- 009.1 Ahuimanu
009.2 Kahaluu segment
009.3 Waihee
- 010.0 Kahana: Kahana
(II) N C D7 7
21°33'35", 157°52'18"
- 010.1 Kahana segment
010.2 Kawa
- 011.0 Kahawainui: Kahuku
(III) N C U 8
21°39'31", 157°55'51"
- 012.0 Kaipapau: Hauula
(II) A I U 2
21°37'13", 157°54'53"
- 013.0 Kalauao: Waipahu
(III) A C D2 5
21°21'57", 157°56'46"
- 014.0 Kalihi: Honolulu
(IV) A C D1 19
21°20'00", 157°53'38"
- 014.1 Kalihi segment
014.2 Kamanaiki
- 015.0 Kaluanui: Hauula
(II) N C D1 4
21°36'05", 157°53'57"
- 016.0 Kaneohe: Kaneohe
(III) A C D3 20
21°24'56", 157°47'09"
- 016.1 Aolani
016.2 Kamooalii
016.3 Kaneohe segment
016.4 Kuou
016.5 Luluku
- 017.0 Kapalama: Honolulu
(IV) A I U 7
21°19'21", 157°52'50"

- 018.0 Kaukonahua: Haleiwa
(III) N C D18 26
21°35'05", 158°07'10"
- 018.1 Kaukonahua segment
018.2 North Poamoho
018.3 Poamoho
018.4 South Kaukonahua
- 019.0 Kaupuni: Waianae
(IV) A I D10 13
21°27'08", 158°11'44"
- 019.1 Hiu
019.2 Honua
019.3 Punanaula
019.4 Kalalula
019.5 Kanewai
019.6 Kauaopuu
019.7 Kaupuni segment
019.8 Kawiwi
019.9 Kukaki
019.10 Kumaipo
- 020.0 Kawa: Kaneohe
(III) A C U 4
21°24'44", 157°47'11"
- 021.0 Keaahala: Kaneohe
(IV) A C U 4
21°25'17", 157°47'23"
- 022.0 Kuliouou: Koko
(III) A I U 4
21°17'18", 157°43'26"
- 023.0 Maakua: Hauula
(II) N I U 2
21°36'50", 157°54'43"
- 024.0 Mailiili: Waianae
(III) A I D3 52
21°25'59", 158°11'05"
- 025.0 Makaha: Waianae
(II) N I D5 7
21°28'38", 158°13'22"
- 026.0 Makaleha: Kaena
(III) A C D3 9
21°34'57", 158°10'11"
- 027.0 Makiki: Honolulu
(IV) A I U 14
21°17'24", 157°50'51"
- 027.1 Kanaha
027.2 Kanealole
027.3 Makiki segment
027.4 Maunalaha
027.5 Moleka
- 028.0 Makua: Kaena
(II) N I D2 1
21°31'12", 158°13'57"
- 029.0 Malaekahana: Kahuku
(III) A I D4 9
21°40'36", 157°56'14"
- 030.0 Manoa: Honolulu
(II) A C D2 30
21°17'24", 157°49'51"
- 030.1 Aihualama
030.2 Luaalaea
030.3 Manoa segment
030.4 Naniuapo
030.5 Palolo
030.6 Pukele
030.7 Waaloa
030.8 Waiakeakua
030.9 Waihi
030.10 Waiomao
- 031.0 Maunawili: Mokapu
(II) A C D8 15
21°25'43", 157°44'40"
- 031.1 Ainoni
031.2 Kahanaiki
031.3 Makawao
031.4 Maunawili segment
031.5 Olomana
031.6 Omao
031.7 Palapu
- 032.0 Moanalua: Honolulu
(III) A I U 39
21°20'05", 157°53'46"
- 032.1 Kahauiki

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047.0 Waimalu: Waipahu
(III) A C D6 9
21°21'52", 156°57'20"

048.0 Waimanalo: Koko
(II) A C D9 13
21°22'05", 157°42'41"

049.0 Waimea R.: Waimea
(II) N C U 7
21°38'40", 158°04'01"

049.1 Elehaha
049.2 Kamananui
049.3 Kawaiwikoele
049.4 Waimea R. segment

Possible Interrupted Streams.

050.0 Kalunawaikaala: Waimea
(III) N I D1 2
21°39'42", 158°03'42"

051.0 Kawaihapai: Kaena
(III) N I D1 3
21°35'01", 158°10'45"

052.0 Kawela: Kahuku
(III) N I D1 4
21°43'05", 158°00'50"

053.0 Pakulena: Waimea
(II) N I U 2
21°39'55", 158°03'24"

054.0 South Makaha: Waianae
(II) N I U 4
21°27'40", 158°12'28"

4. Kauai Island.

001.0 Aakukui: Hanapepe
(III) N I D4 6
21°56'31", 159°39'12"

002.0 Anahola: Anahola
(III) N C D6 6
22°09'11", 159°18'30"

002.1 Anahola segment
002.2 Kaalula
002.3 Kahoopulu
002.4 Kaupaku
002.5 Keaopu

003.0 Anini: Hanalei
(III) A C U 3
22°13'34", 159°28'00"

004.0 Awaawapuhi: Makaha
(I) N C U 0
22°09'59", 159°41'27"

005.0 East Waiakalua: Anahola
(II) N C D1 4
22°13'07", 159°22'33"

006.0 East Waipake: Anahola
(III) N C U 1
22°12'53", 159°21'06"

007.0 Haeleele: Makaha
(II) N I U 0
22°05'51", 159°45'05"

008.0 Hanakapiai: Haena
(II) N C U 0
22°12'46", 159°36'01"

009.0 Hanakoa: Haena
(I) N C U 0
22°11'53", 159°37'36"

010.0 Hanalei R.: Hanalei
(II) N C D6 6
22°13'05", 159°30'01"

010.1 Hanalei R. segment
010.2 Kaapoko
010.3 Waipunaea

011.0 Hanamaulu: Kapaa
(III) N C D13 10
21°59'21", 159°20'34"

012.0 Hanapepe: Hanapepe
(III) A C D14 10
21°54'24", 159°35'36"

012.1 Hanapepe segment
012.2 Hauhili
012.3 Kalai
012.4 Kapohakukilomanu
012.5 Kawaipua
012.6 Koula
012.7 Wainonoia

013.0 Hoolulu: Haena
(I) N C U 0
22°12'30", 159°36'41"

014.0 Honopu: Makaha
(I) N C U 0
22°10'46", 159°40'36"

015.0 Hikimoe: Makaha
(II) N I U 0
22°06'24", 159°44'46"

016.0 Huleia: Lihue
(III) A C D40 38
21°57'03", 159°21'52"

016.1 Halenahanu
016.2 Hoinakaunalehua
016.3 Huleia segment
016.4 Kamooloa
016.5 Kuia
016.6 Paohia
016.7 Papakolea
016.8 Papuaa
016.9 Puakukui
016.10 Puhi
016.11 Weoweopilau

017.0 Kaaweiki: Makaha
(II) N I U 0
22°06'47", 159°44'36"

- 018.0 Kalalau: Haena
(I) N C U 0
22°10'53", 159°39'18"
- 019.0 Kalihiwai R.: Hanalei
(II) N C D3 2
22°13'11", 159°24'53"
- 019.1 Kalihiwai R. segment
019.2 Kaumoku
019.3 Pouli
- 020.0 Kapaa: Kapaa
(III) N C D10 13
22°05'46", 159°18'00"
- 020.1 Kapaa segment
020.2 Kapahi
020.3 Kealia
020.4 Maiakii
020.5 Makaleha
020.6 Moalepe
020.7 Mimino
- 021.0 Kauhao: Makaha
(II) N I U 0
22°07'16", 159°44'27"
- 022.0 Kaulaula: Makaha
(II) N I U 0
22°05'35", 159°45'22"
- 023.0 Kilauea: Anahola
(II) A C D12 7
22°13'22", 159°23'20"
- 023.1 Halaulani
023.2 Kahiliholo
023.3 Kaluamakua
023.4 Kilauea segment
023.5 Pohakuhonu
023.6 Puu Ka Ele
023.7 Wailapa
- 024.0 Konohiki: Kapaa
(III) A C D2 12
22°04'26", 159°19'02"
- 025.0 Kulihaili: Anahola
(II) N C U 1
22°13'08", 159°22'38"
- 026.0 Kumukumu: Kapaa
(IV) A C D4 8
22°06'38", 159°17'58"
- 027.0 Lawai: Koloa
(II) A C D3 10
21°53'30", 159°30'20"
- 028.0 Limahuli: Haena
(II) N C U 1
22°13'41", 159°34'37"
- 029.0 Lumahai R.: Hanalei
(II) N C U 1
22°13'12", 159°32'06"
- 030.0 Mahinauli: Hanapepe
(III) N C D7 8
21°55'56", 159°38'52"
- 031.0 Makaha: Makaha
(II) N I U 0
22°08'34", 159°44'00"
- 032.0 Manoa: Haena
(II) N C D1 1
22°13'29", 159°34'06"
- 033.0 Maunapuluo: Haena
(II) N C U 0
22°12'56", 159°35'55"
- 034.0 Milolii: Makaha
(I) N C U 0
22°09'10", 159°43'31"
- 035.0 Moloaa: Anahola
(III) N C U 3
22°11'54", 159°20'12"
- 035.1 Kaluua
035.2 Moloaa segment
- 036.0 Nahomalu: Kekaha
(II) N I D4 2
22°02'43", 159°46'30"
- 037.0 Nakeikionaiwi: Haena
(I) N C U 0
22°10'33", 159°39'46"

038.0 Nawiliwili: Lihue
(IV) N C D8 16
21°57'47", 159°21'16"

039.0 Nualolo: Makaha
(I) N C U 0
22°09'56", 159°41'49"

040.0 Papaa: Anahola
(III) N C D1 7
22°10'38", 159°19'00"

041.0 Pilaa: Anahola
(II) N C U 1
22°12'52", 159°22'02"

042.0 Pohakuao: Haena
(I) N C U 0
22°11'24", 159°38'18"

043.0 Puali: Lihue
(II) N C D7 9
21°57'17", 159°21'50"

043.1 Halehaka

043.2 Puali segment

044.0 Puukumu: Hanalei
(III) A C U 5
22°13'11", 159°24'53"

045.0 Wahiawa: Hanapepe
(III) N C D4 4
21°53'38", 159°34'41"

046.0 Waiahuakua: Haena
(I) N C U 0
22°12'12", 159°37'04"

047.0 Waikoko: Hanalei
(III) A I U 1
22°12'36", 159°31'08"

048.0 Waikomo: Koloa
(III) A C D9 17
21°52'59", 159°28'16"

048.1 Omao

048.2 Poeleele

048.3 Waihohonu

048.4 Waikomo segment

049.0 Wailua R.: Kapaa
(III) N C D32 27
22°02'55", 159°20'19"

049.1 Halii

049.2 Iliiliula

049.3 Iole

049.4 Kalama

049.5 Kaulu

049.6 Kawi

049.7 Keahua

049.8 North Fork Wailua

049.9 Opaekaa

049.10 Palikea

049.11 South Fork Wailua

049.12 Uhau Iole

049.13 Waiahi

049.14 Waiaka

049.15 Waikoko

049.16 Wailua R. segment

050.0 Waimea R.: Kekaha
(III) A C D28 10
21°57'16", 159°40'07"

050.1 Awini

050.2 Elekeniiki

050.3 Elekeninui

050.4 Halehaha

050.5 Halekua

050.6 Halemanu

050.7 Halepaakai

050.8 Kauaikinana

050.9 Kawaikoi

050.10 Koale

050.11 Koholoina

050.12 Kokee

050.13 Loli

050.14 Makaweli

050.15 Maluapopoki

050.16 Mohihi

050.17 Mokihana

050.18 Mokuone

050.19 Nawaimaka

050.20 Noe

050.21 Olokole

050.22 Poomau

050.23 Waiahulu

050.24 Waiakoali

050.25 Waialae

050.26 Waianuenue

050.27 Waiau
050.28 Waimea R. segment

051.0 Wainiha R.: Haena
(II) N C D19 9
22°13'03", 159°32'29"

051.1 Hiaupe
051.2 Makawea
051.3 Maunahina
051.4 Wainiha segment

052.0 Waipa: Hanalei
(III) N C U 1
22°12'25", 159°30'58"

053.0 Waipao: Hanapepe
(III) A C D5 5
21°56'39", 159°39'23"

054.0 Waioli: Hanalei
(III) N C U 1
22°12'22", 159°30'47"

055.0 West Waipake: Anahola
(III) N C D3 6
22°13'00", 159°21'10"

Possible Interrupted Stream.

056.0 Aliomanu: Anahola
(III) N I U 4
22°09'52", 159°18'30"

5. Molokai.

001.0 Anapuhi: Kamalo
(I) N C U 0
21°10'02", 156°54'34"

002.0 Halawa: Halawa
(I) N C U 0
21°09'46", 156°44'23"

002.1 Halawa segment
002.2 Hipuapua
002.3 Moalua
002.4 Nawaihilili

003.0 Haloku: Kamalo
(I) N I U 0
21°09'57", 156°51'42"

004.0 Honoulimaloo: Halawa
(I) N I U 1
21°07'01", 156°44'36"

005.0 Honouliwai: Halawa
(I) N C U 1
21°06'51", 156°44'54"

006.0 Kahananui: Kamalo
(I) N I U 1
21°03'30", 156°50'16"

007.0 Kahiwa: Halawa
(I) N C U 0
21°10'36", 156°48'33"

008.0 Kailiili: Kamalo
(I) N C U 0
21°09'52", 156°53'08"

009.0 Kainalu: Halawa
(I) N I U 1
21°05'22", 156°46'35"

010.0 Kalaemilo: Halawa
(I) N C U 0
21°10'31", 156°49'12"

011.0 Kaluaaha: Kamalo
(I) N I U 0
21°03'54", 156°49'37"

012.0 Kamalo: Kamalo
(I) A I U 1
21°03'02", 156°56'07"

013.0 Kawainui: Halawa
(II) N C U 0
21°10'15", 156°47'53"

013.1 Kapea
013.2 Kawainui segment

014.0 Kawela: Kaunakakai
(II) N I D4 1
21°04'00", 156°57'11"

015.0 Keawanui: Kamalo
(I) N C U 0
21°10'10", 156°53'42"

016.0 Mapulehu: Halawa
(I) N I U 1
21°04'12", 156°48'18"

017.0 Ohia: Kamalo
(I) N I U 1
21°03'26", 156°50'36"

018.0 Oloupena: Kamalo
(I) N I U 0
21°09'57", 156°51'32"

019.0 Pelekunu: Kamalo
(I) N C U 0
21°09'51", 156°52'59"

019.1 Kapuhi
019.2 Kawaiiki
019.3 Kawailena
019.4 Kawainui
019.5 Kawaipaka
019.6 Lanipuni
019.7 Pelekunu segment
019.8 Pilipililau

020.0 Pipiwai: Halawa
(I) N I U 0
21°10'41", 156°45'45"

021.0 Pohakupili: Halawa
 (I) N I U 1
 21°07'45", 156°43'57"

022.0 Puukaoku: Kamalo
 (I) N I U 0
 21°09'58", 156°51'20"

023.0 Waiahookalo: Kamalo
 (I) N C U 0
 21°10'32", 156°48'55"

024.0 Waialeia: Kamalo
 (II) N C D1 0
 21°10'33", 156°56'43"

025.0 Waialua: Halawa
 (II) N C U 1
 21°05'56", 156°45'46"

026.0 Waihanau: Kaunakakai
 (II) N I D1 1
 21°11'20", 156°59'14"

027.0 Waikolu: Kamalo
 (III) N C D1 0
 21°10'22", 156°55'59"

028.0 Wailau: Kamalo
 (I) N C U 0
 21°10'06", 156°49'52"

028.1 Kahawaiiki
 028.2 Pulena
 028.3 Waiakeakua
 028.4 Wailau segment
 028.5 Waiokeela

029.0 Wailele: Kamalo
 (I) N I U 0
 21°10'02", 156°51'12"

030.0 Wainene: Kamalo
 (I) N C U 0
 21°10'15", 156°55'01"

031.0 Waiohookalo: Halawa
 (I) N C U 0
 21°09'55", 156°54'00"

032.0 Waipu: Kamalo
 (I) N I U 0
 21°09'50", 156°52'03"

033.0 Wawaia: Kamalo
 (I) N I U 1
 21°03'07", 156°52'12"

Possible Interrupted Streams.

034.0 Ahaino: Halawa
 (I) N I U 1
 21°05'00", 156°47'14"

035.0 Honomuni: Halawa
 (I) N I U 1
 21°05'09", 156°46'53"

036.0 Kaunakakai: Kaunakakai
 (II) N I D3 1
 21°05'26", 157°01'52"

037.0 Manawai: Kamalo
 (I) N I U 1
 21°03'29", 156°50'28"







Appendix B. Maps of Altered Hawaiian Streams Showing Extent of Watersheds, Positions of Mainstreams and Tributaries, Longitudinal Gradients, Types and Approximate Locations of the Alterations, and Locations of Collection Sites with List of Faunal Species Collected

Stream maps are arranged by island. Streams for each island are preceded by a locator map of the island showing stream locations. The arrangement of maps is:

Locator map for Hawaii - Figure B1;
Hawaii stream maps - Figures B2 through B5;
Locator map for Maui - Figure B6;
Maui stream maps - Figures B7 through B13;
Locator map for Oahu - Figure B14;
Oahu stream maps - Figures B15 through B47;
Locator map for Kauai - Figure B48
Kauai stream maps - Figures B49 through B61;
Locator map for Molokai - Figure B62;
Molokai stream map - Figure B63.

LEGEND FOR APPENDIX

Symbols for Alteration Types (Maps)

- | | | |
|-----|--|---|
| (1) |  | Lined channel. An artificial channel having both natural banks and stream bed replaced, usually with concrete. May be flat bottom or v-shaped. |
| (2) |  | Channel realigned and/or vegetation removed. |
| (3) |  | Elevated culvert. Conduit structures that are comparatively short (typically <60 meters), usually found under highways. Culverts that discharge at stream level have been excluded. |
| (4) |  | Revetment. One or both banks of the stream are reinforced but the channel bed is not. |
| (5) |  | Blocked or filled-in channel. Part of the original channel is blocked. |
| (6) | 
<hr/> | Extended culvert. A longer version of modification type 3, usually found in residential areas. |

Abbreviation Coding for Faunal Species

Crustacea.

Ab = Atya bisulcata

Mg = Macrobrachium grandimanus

Ml = Macrobrachium lar

Pc = Procambarus clarkii

Pisces.

Ag = Awaous genivittatus

As = Awaous stamineus

Cc = Cyprinus carpio

Cf = Clarias fuscus

Cs = Cichlasoma sp

Es = Eleotris sandwicensis

Ga = Gambusia affinis

Ks = Kuhlia sandwicensis

Lc = Lentipes concolor

Lm = Lepomis macrochirus

Ma = Misgurnus anguillicaudatus

Md = Micropterus dolomieu

Os = Ophicephalus striatus

Pl = Poecilia latipinna

Pm = Poecilia mexicana

Pr = Poecilia reticulata

Pv = Poecilia vittata

Ss = Sicydium stimpsoni

Tm = Tilapia mossambica

Xh = Xiphophorus helleri

Xm = Xiphophorus maculatus

Symbols for Species Abundances

0 = Rare or occasional, not more than one specimen collected per sampling or only occasionally collected; sometimes sighted but not captured.

○ = Common, between two and five specimens obtained per sampling.

● = Abundant, more than five specimens per sampling.

Symbols for Stream Channels and Watershed

— = Continuous portion of channel of a perennial stream.

- - - = Interrupted portion of channel of a perennial stream.

..... = Boundary of stream watershed.

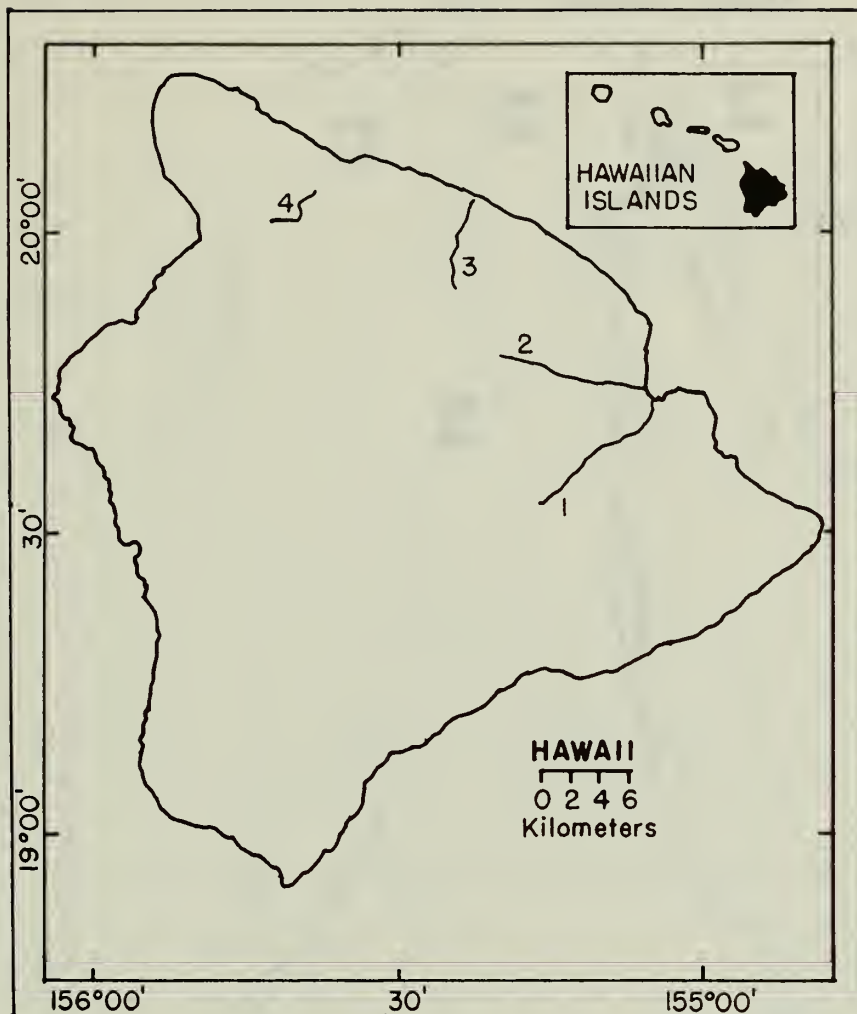


Figure B1. Locator map for four Hawaii streams having modified channels.

Legend:

1. Wailoa River
2. Pukihae Stream
3. Papuaa Stream
4. Lamimaumau Stream

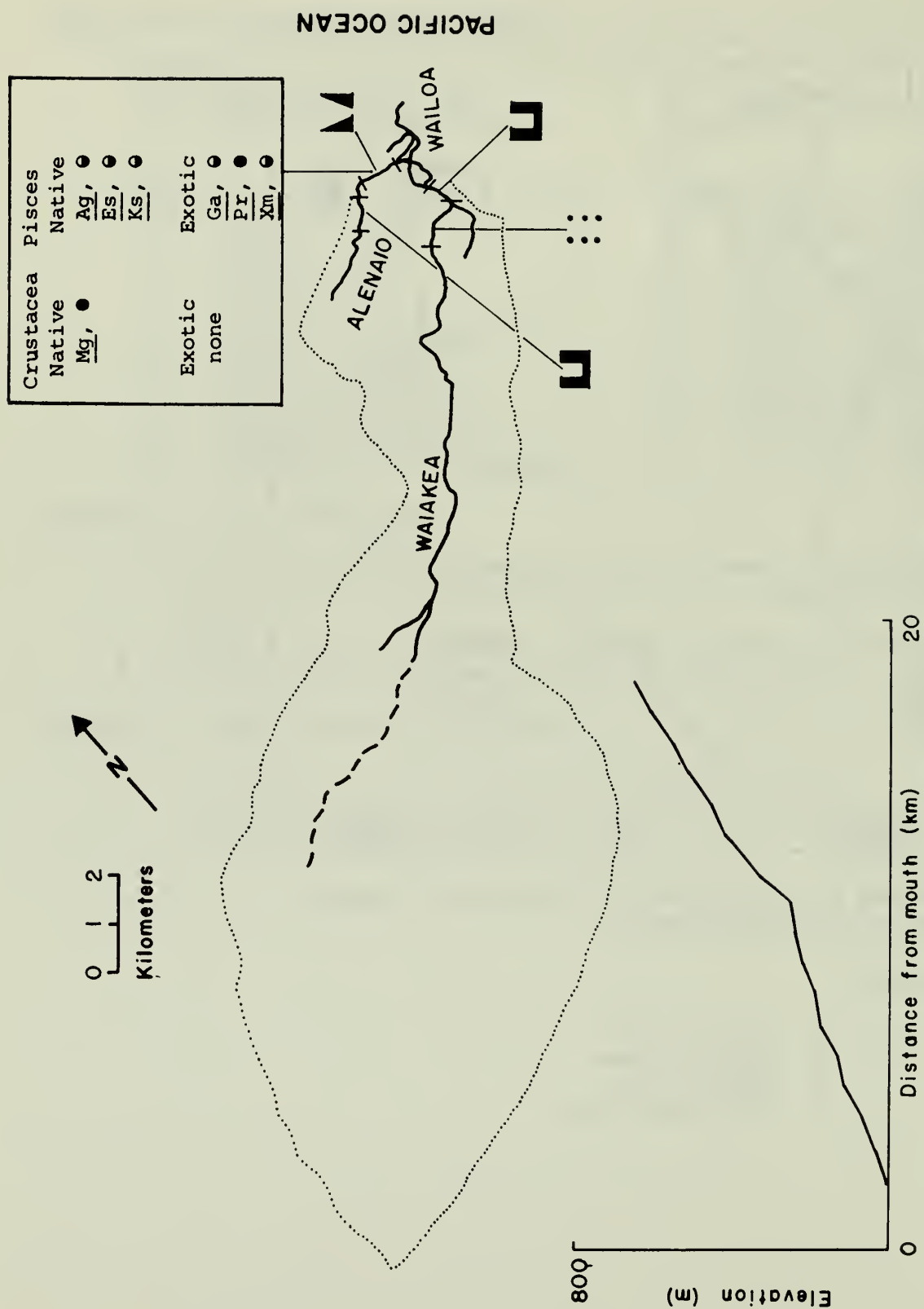


Figure B2. Wailoa River, Hawaii: 12% of channel altered. Longitudinal gradient (m/km) = 36.

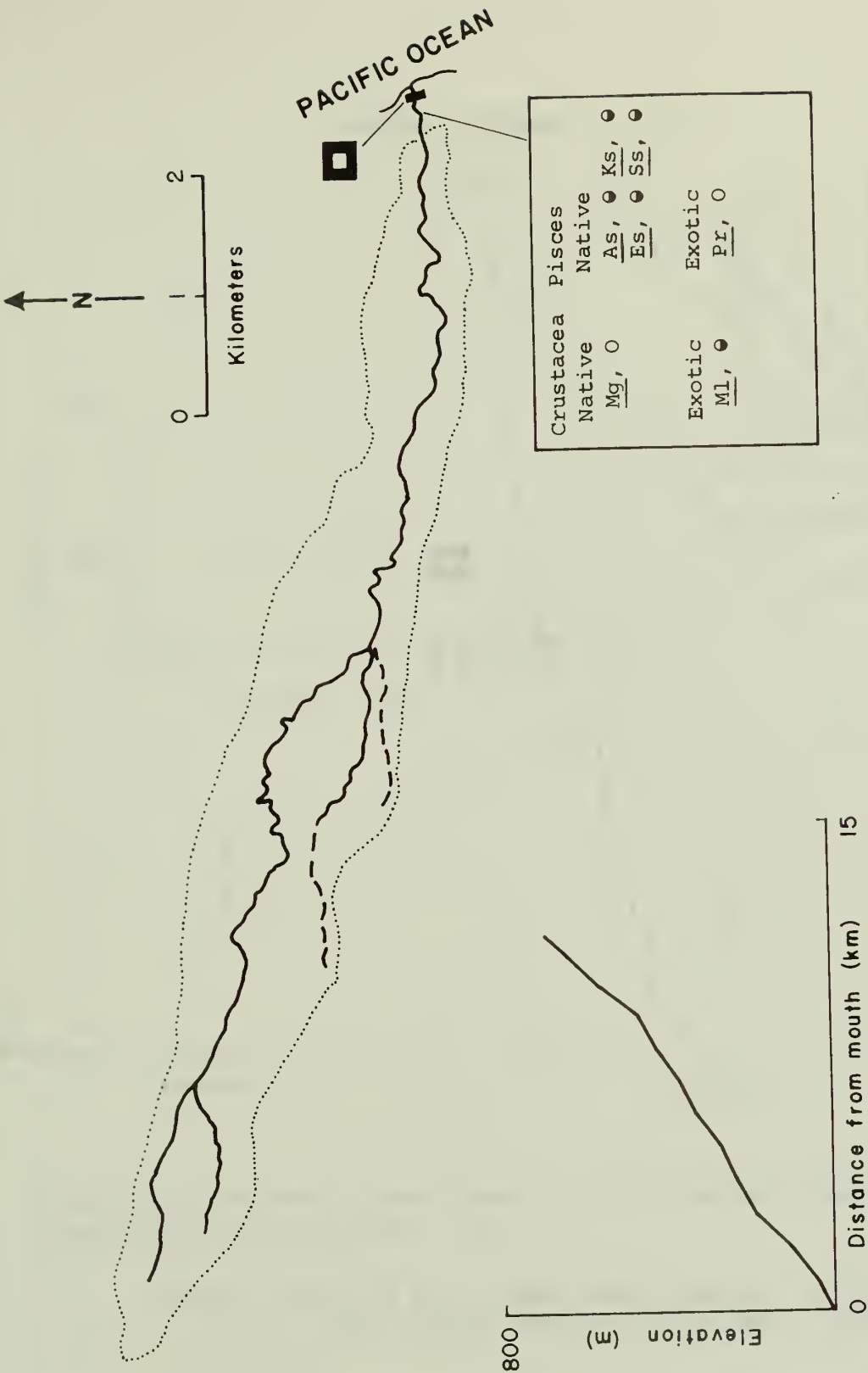


Figure B3. Pukihāe Stream, Hawaii: <1% of channel length altered. Longitudinal gradient (m/km) = 58.

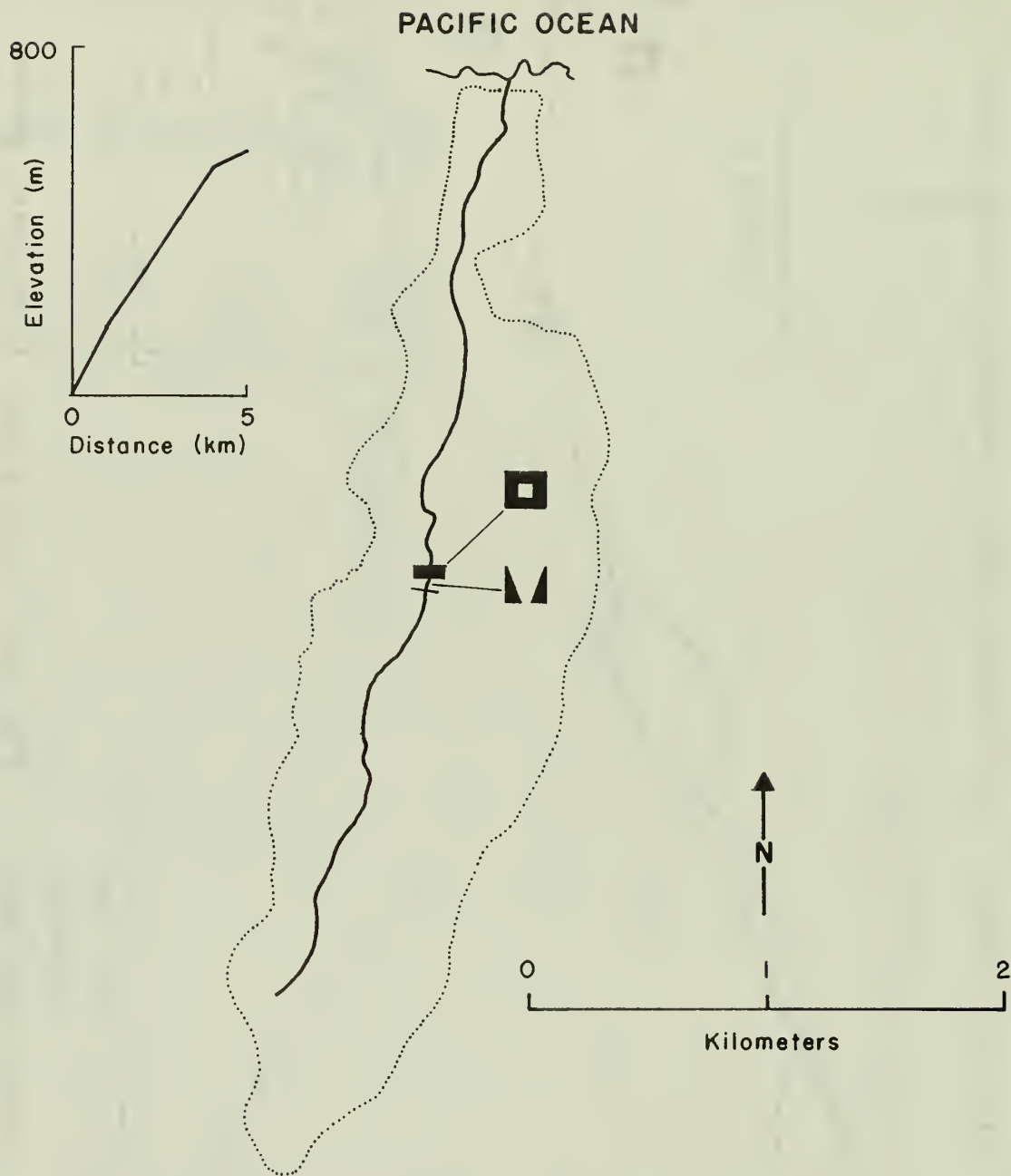


Figure B4. Papuaa Stream, Hawaii: 2% of channel length altered. Longitudinal gradient (m/km) = 123.

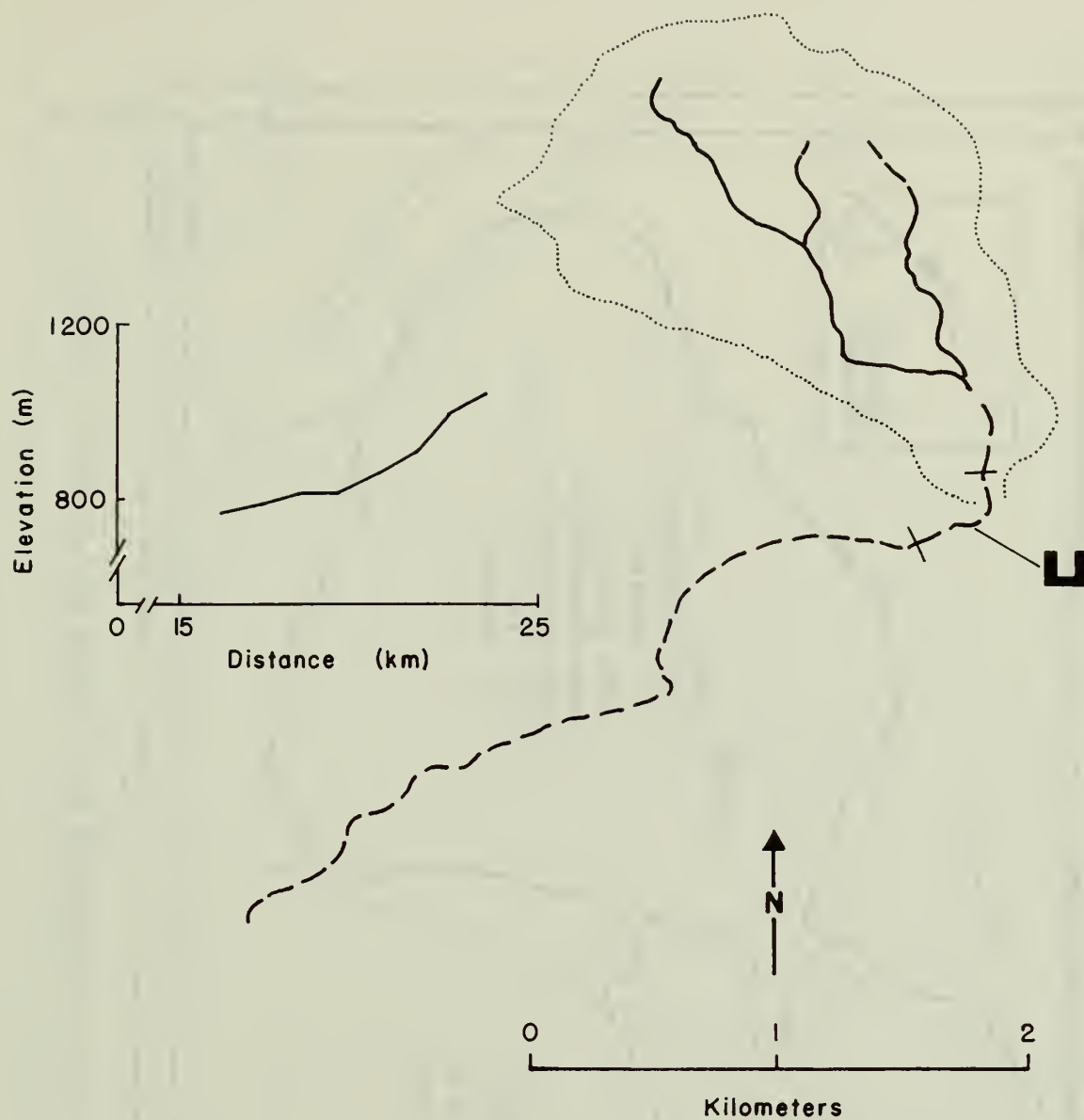


Figure B5. Lamimaumau Stream, Hawaii: 10% of channel length altered. Longitudinal gradient (m/km) = 36.

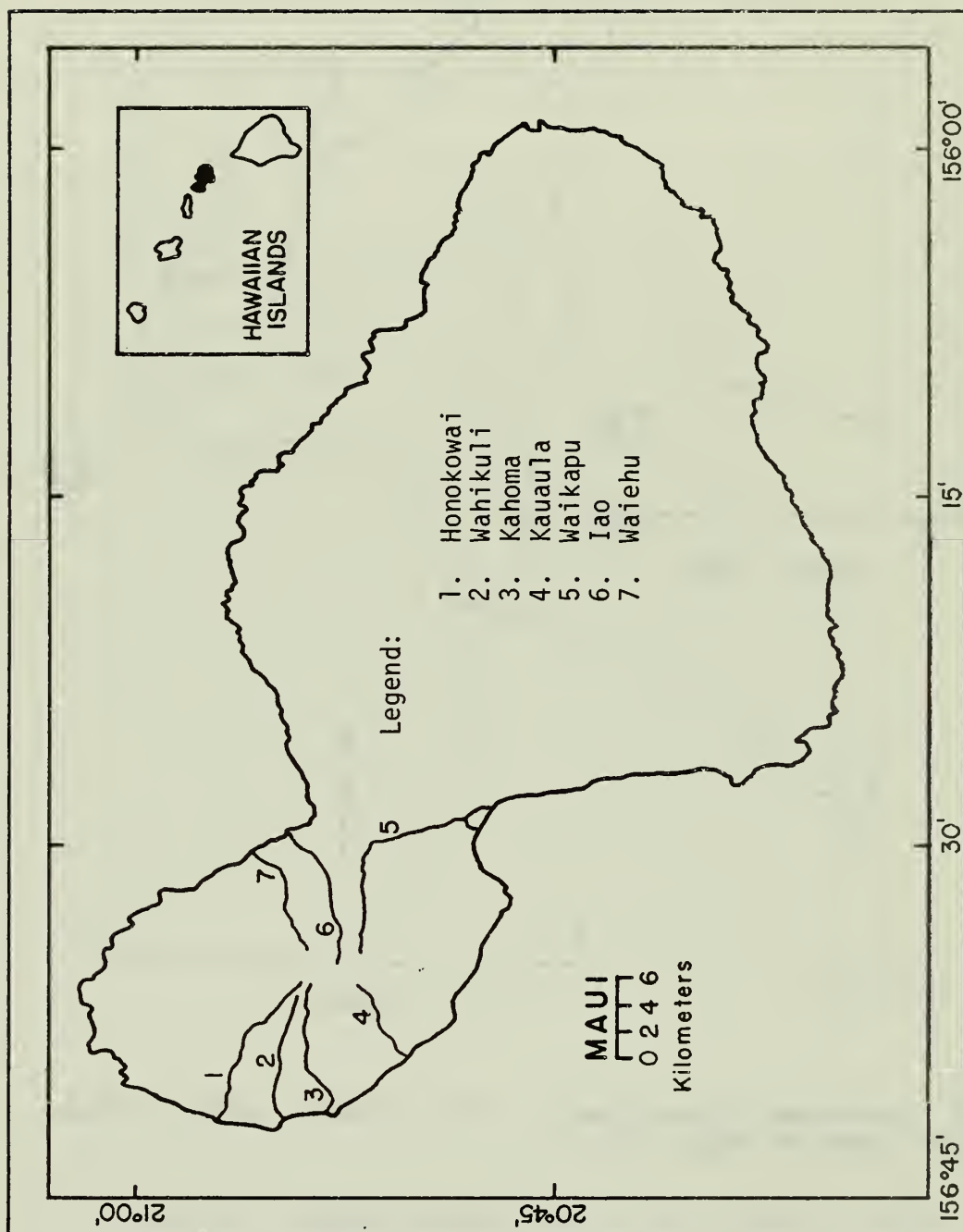


Figure B6. Locator map for seven Maui streams having modified channels.

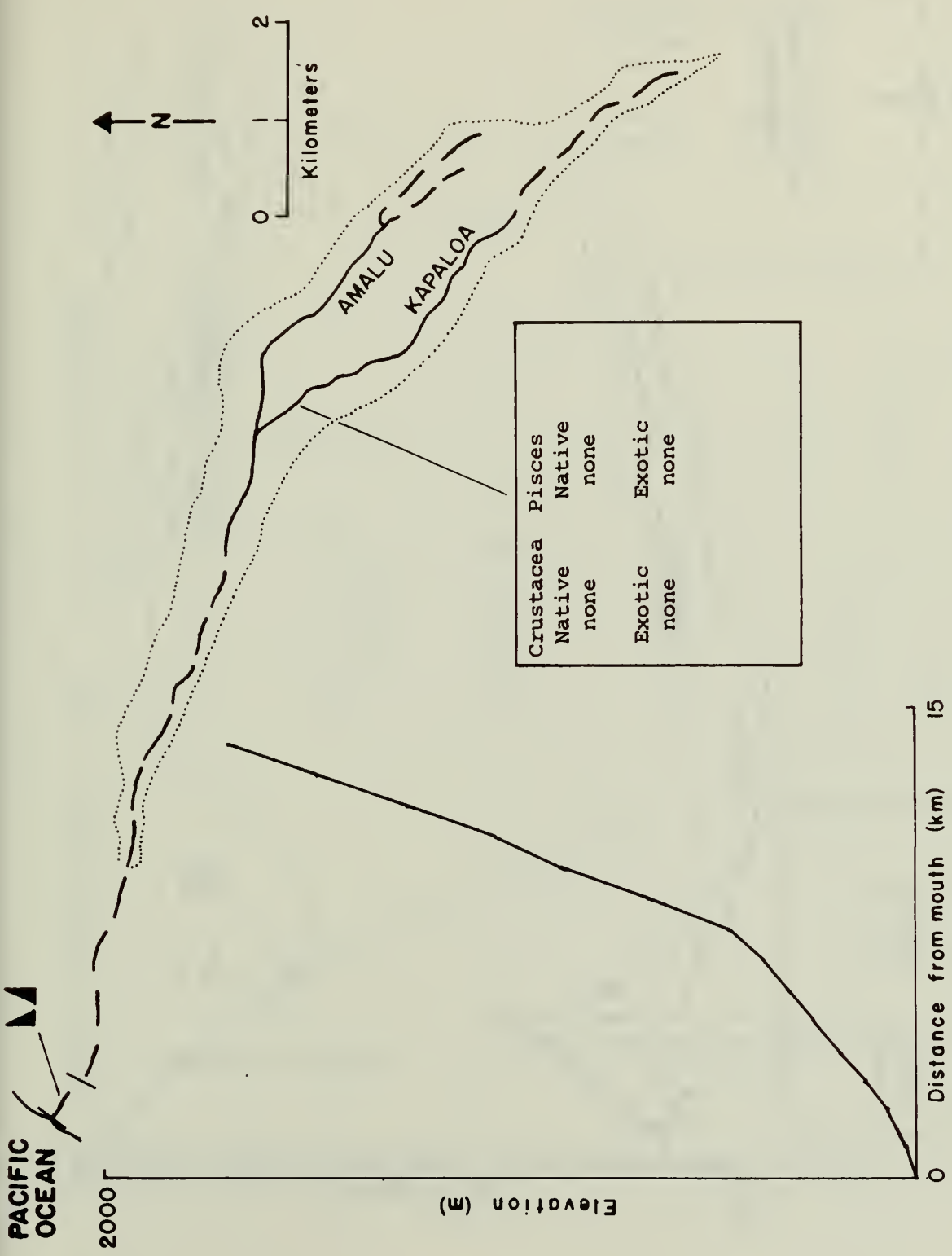


Figure B7. Honokowai Stream, Maui: 2% of channel length altered. Longitudinal gradient (m/km) = 120.

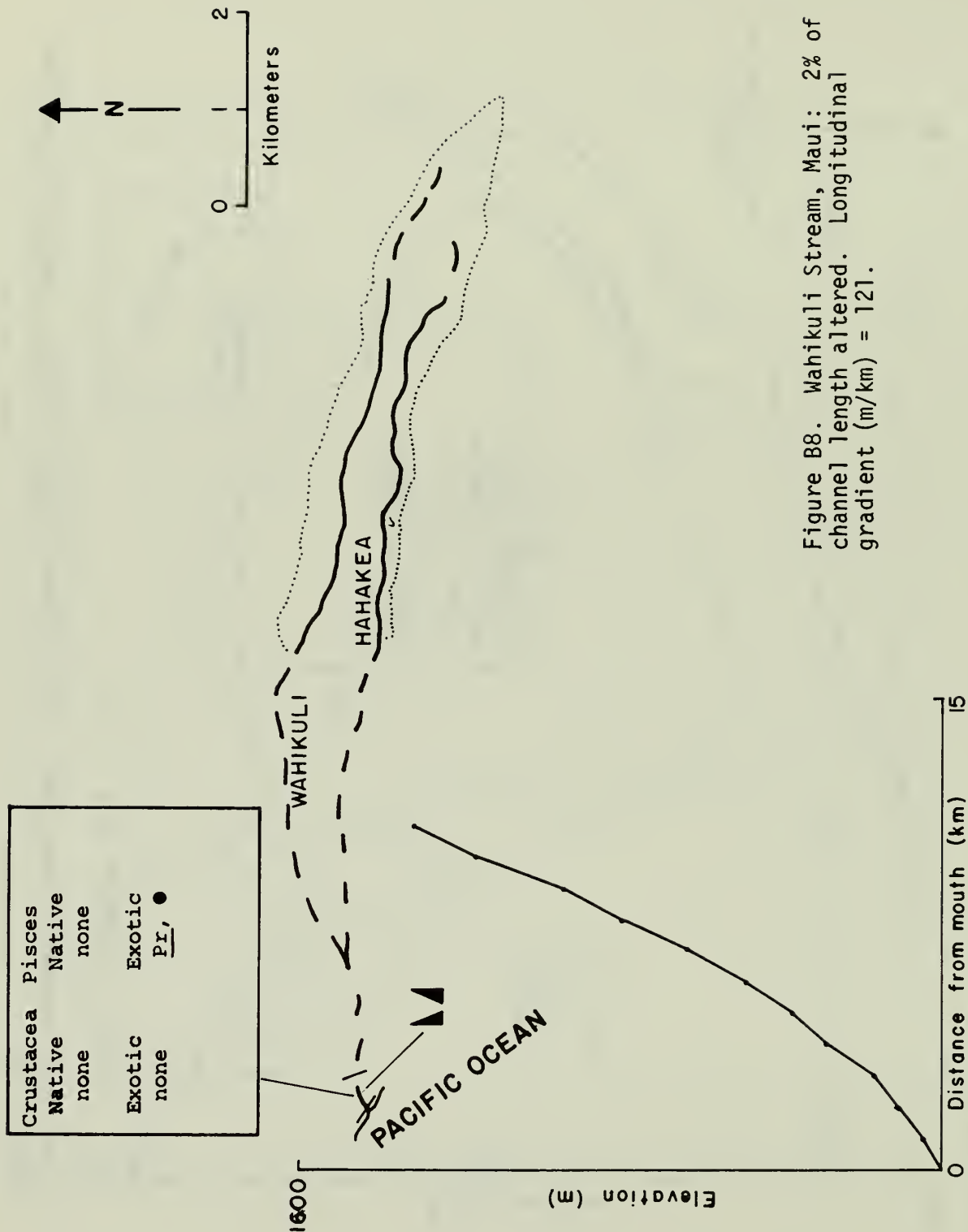


Figure B8. Wahikuli Stream, Maui: 2% of channel length altered. Longitudinal gradient (m/km) = 121.

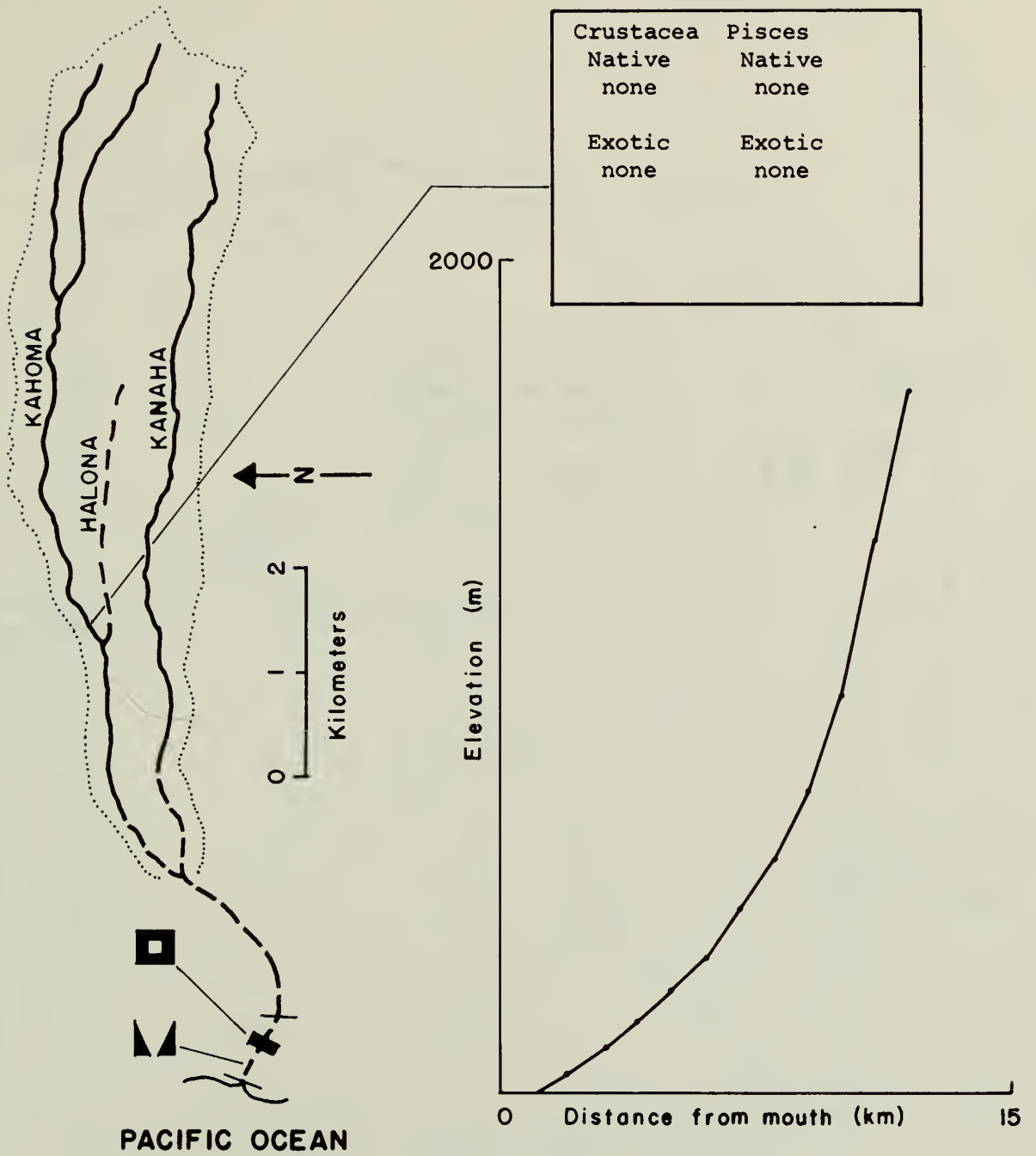


Figure B9. Kahoma Stream, Maui: 4% of channel length altered.
 Longitudinal gradient (m/km) = 140.

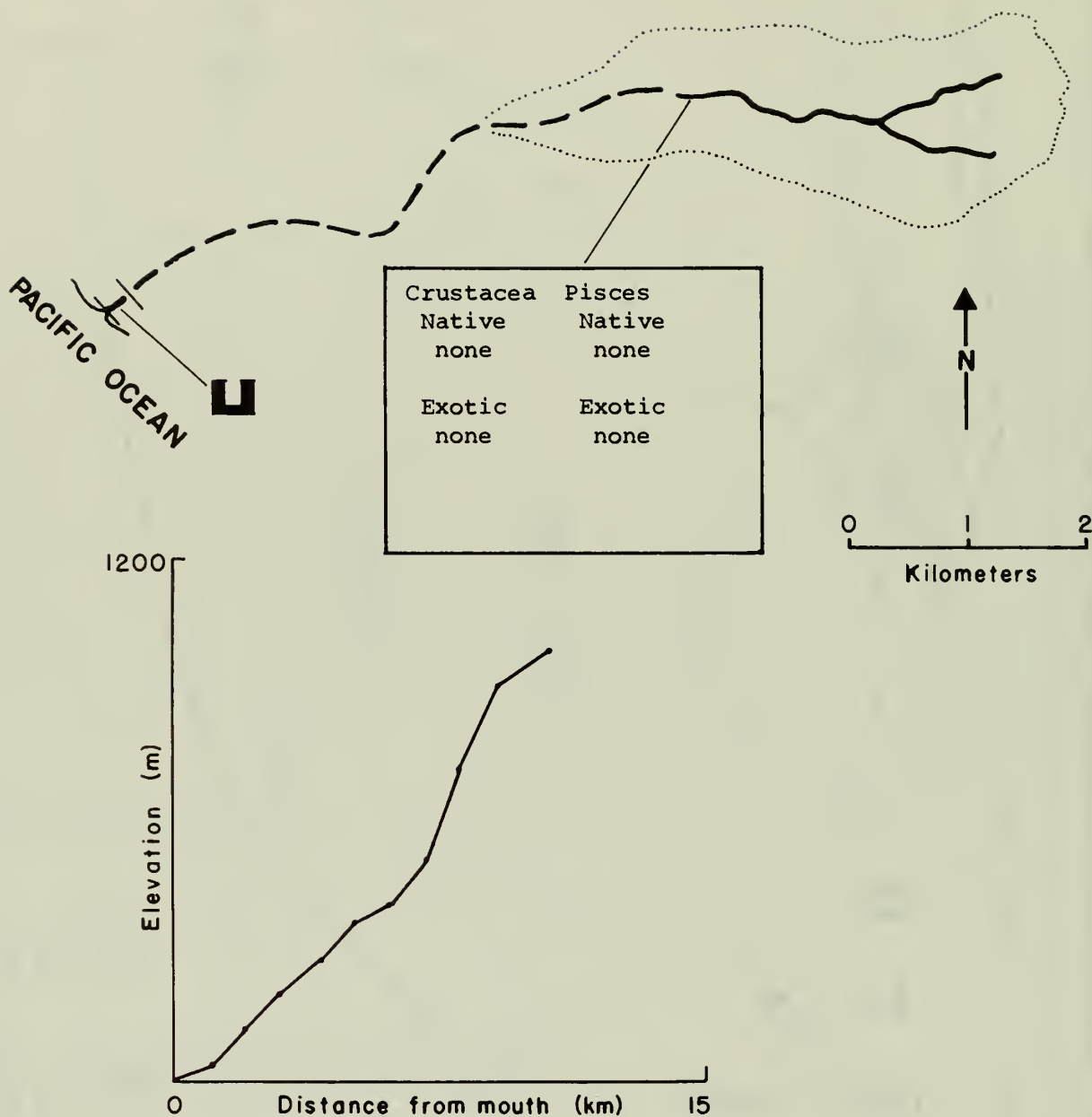


Figure B10. Kauaula Stream, Maui: 3% of channel length altered. Longitudinal gradient (m/km) = 108.

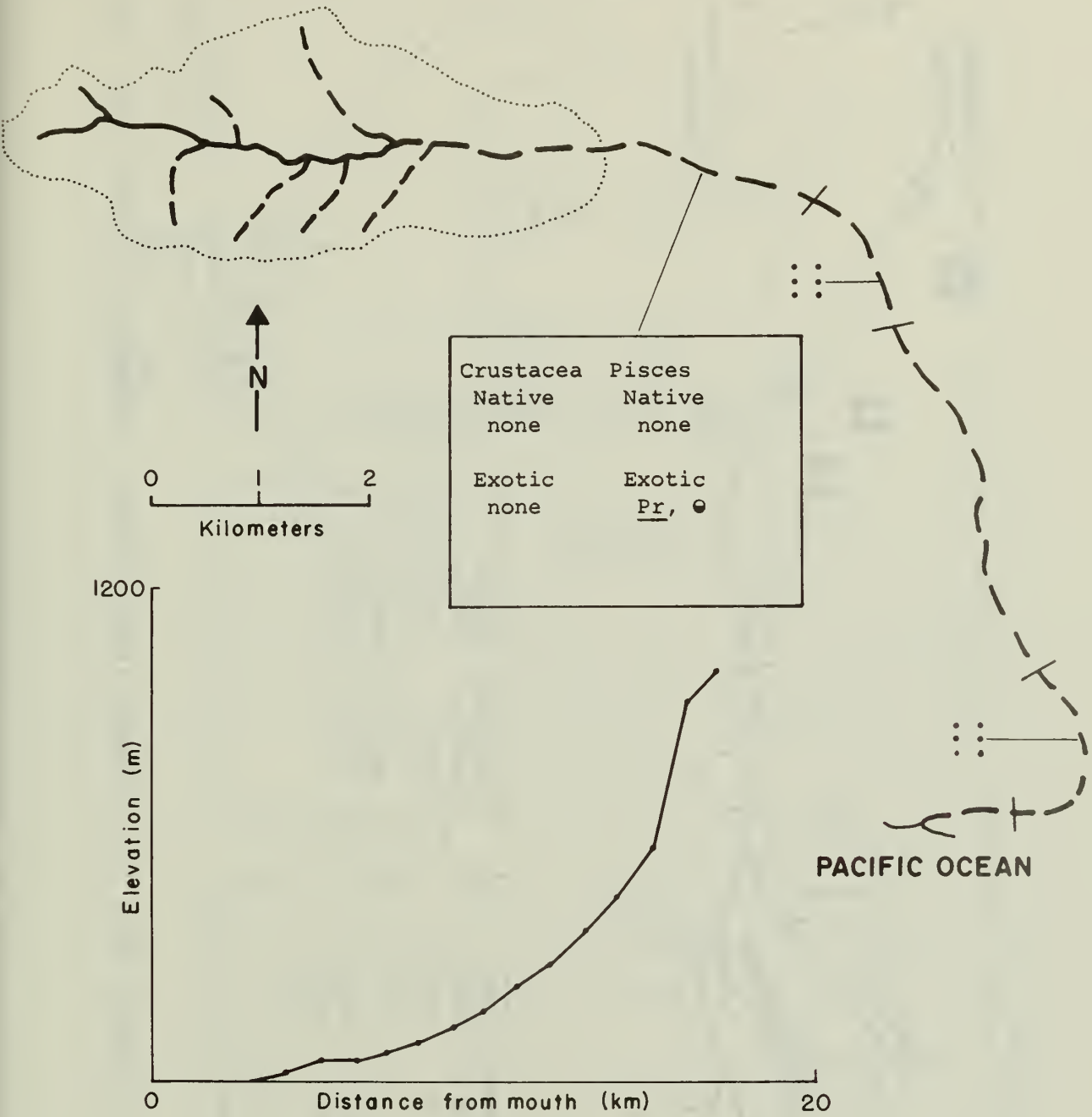


Figure B11. Waikapu Stream, Maui: 11% of channel length altered.
 Longitudinal gradient (m/km) = 63.

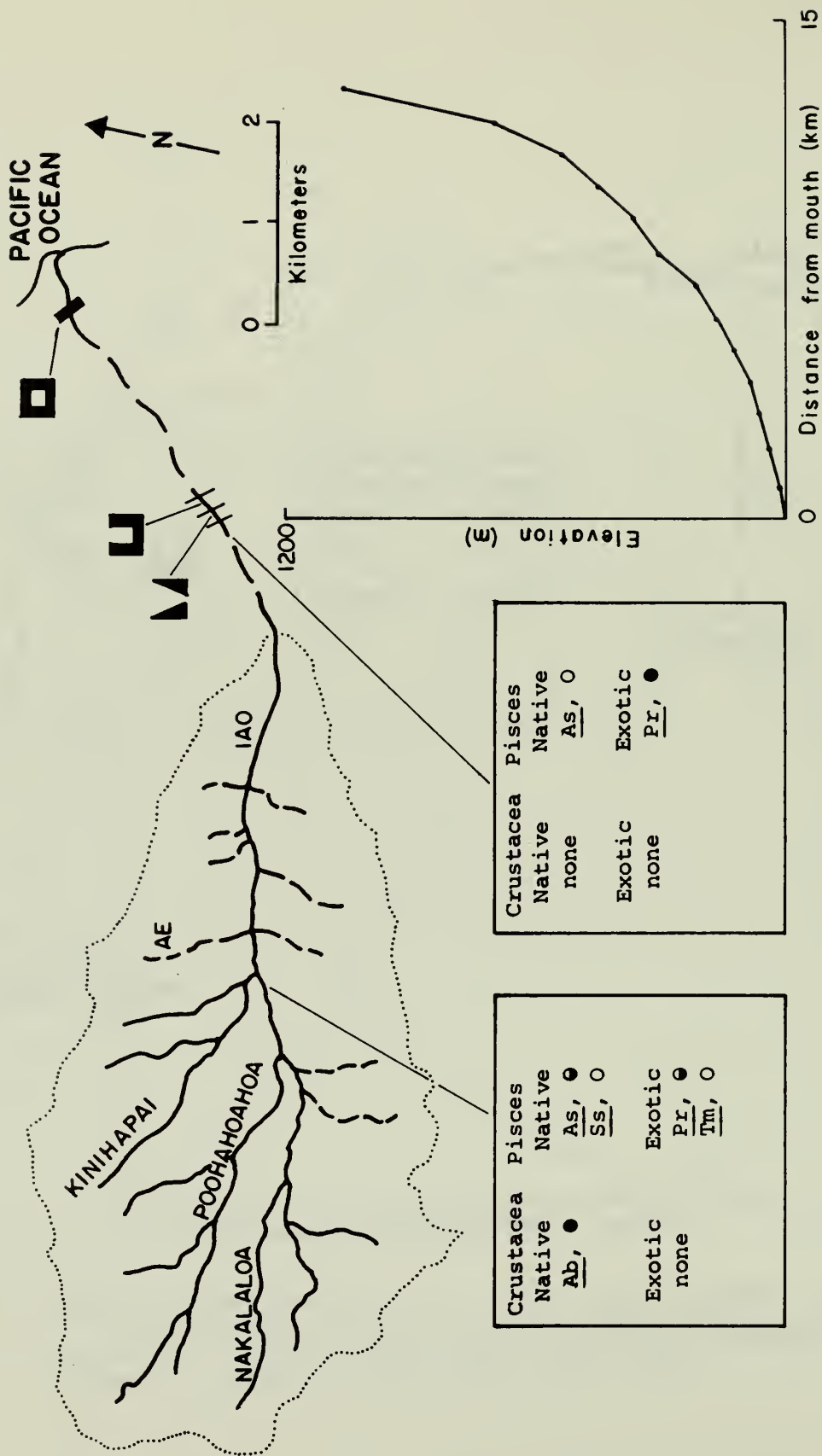


Figure B12. Iao Stream, Maui: 1% of channel length altered. Longitudinal gradient (m/km) = 80.

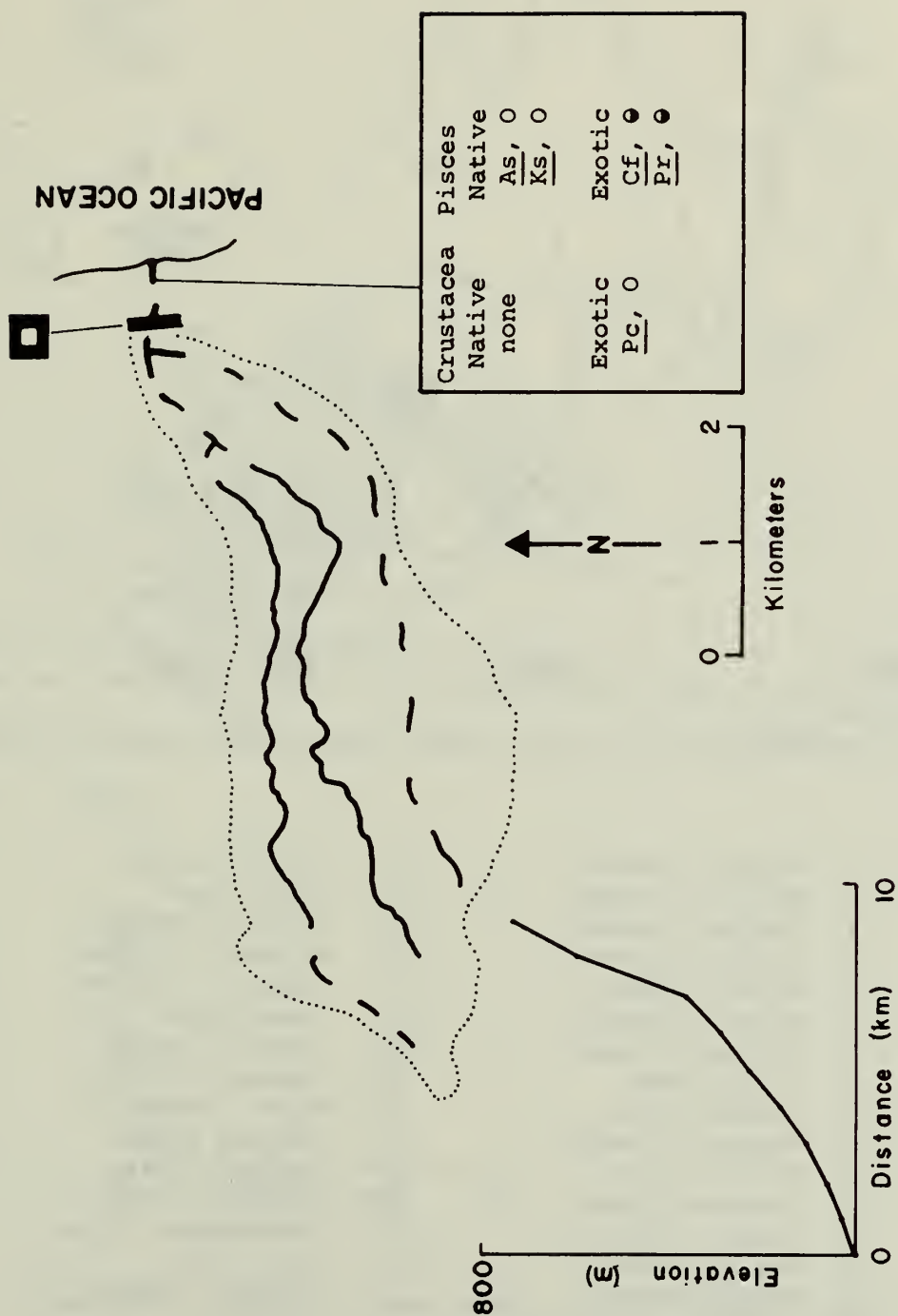


Figure B13. Waiehu Stream, Maui: <1% of channel length altered. Longitudinal gradient (m/km) = 91.

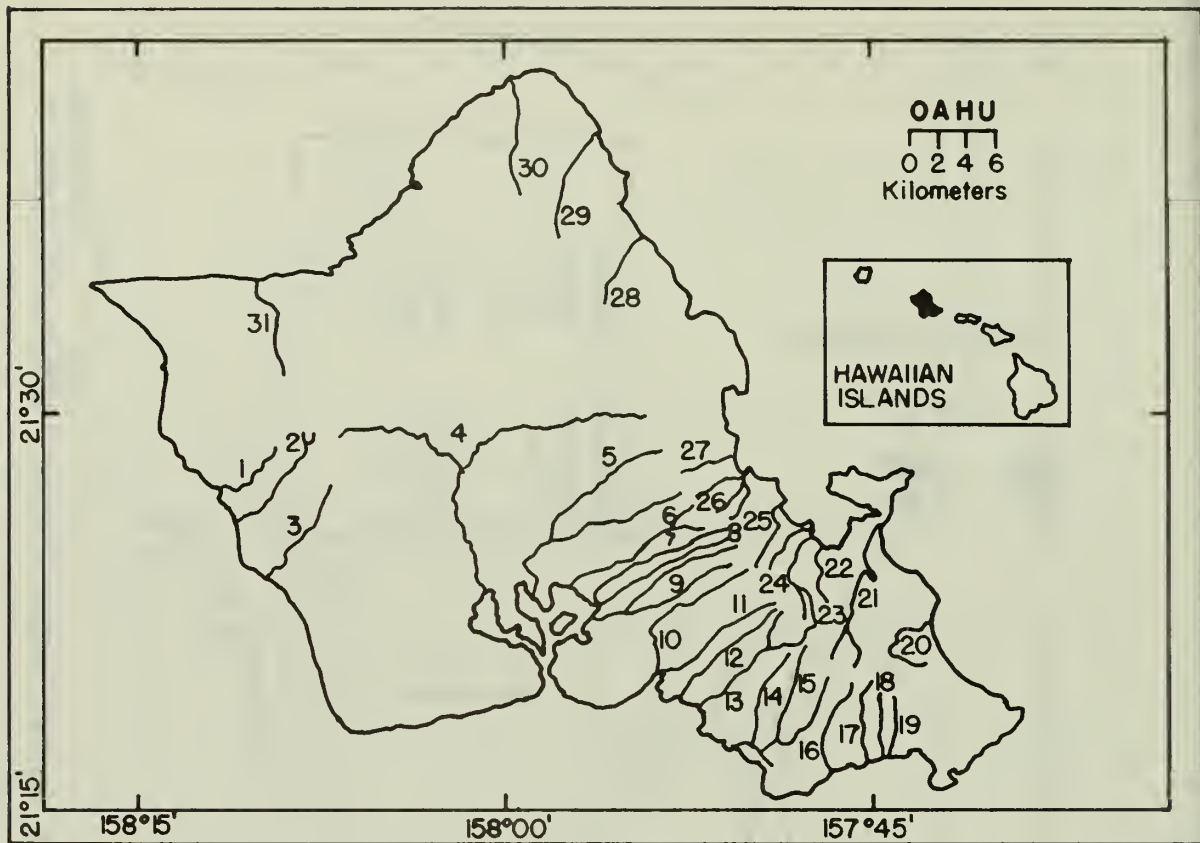


Figure B14. Locator map for the 31 Oahu Streams having modified channels.

Legend:

- | | |
|-----------------------|------------------------|
| 1. Kaupuni Stream | 17. Wailupe Stream |
| 2. Mailiili Stream | 18. Pia Stream |
| 3. Ulehawa Stream | 19. Kuliouou Stream |
| 4. Waikele Stream | 20. Waimanalo Stream |
| 5. Waiawa Stream | 21. Maunawili Stream |
| 6. Waimalu Stream | 22. Kawa Stream |
| 7. Kalauao Stream | 23. Kaneohe Stream |
| 8. Aiea Stream | 24. Keaahala Stream |
| 9. Halawa Stream | 25. Heeia Stream |
| 10. Moanalua Stream | 26. Kahaluu Stream |
| 11. Kalihi Stream | 27. Kaalaea Stream |
| 12. Kapalama Stream | 28. Kaipapau Stream |
| 13. Nuuanu Stream | 29. Malaekahana Stream |
| 14. Makiki Stream | 30. Oio Stream |
| 15. Manoa Stream | 31. Makaleha Stream |
| 16. Waialaenui Stream | |

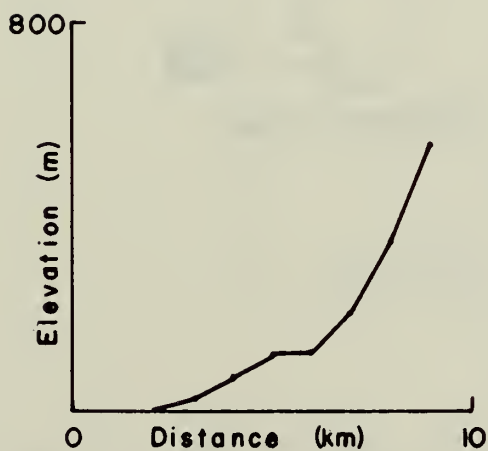
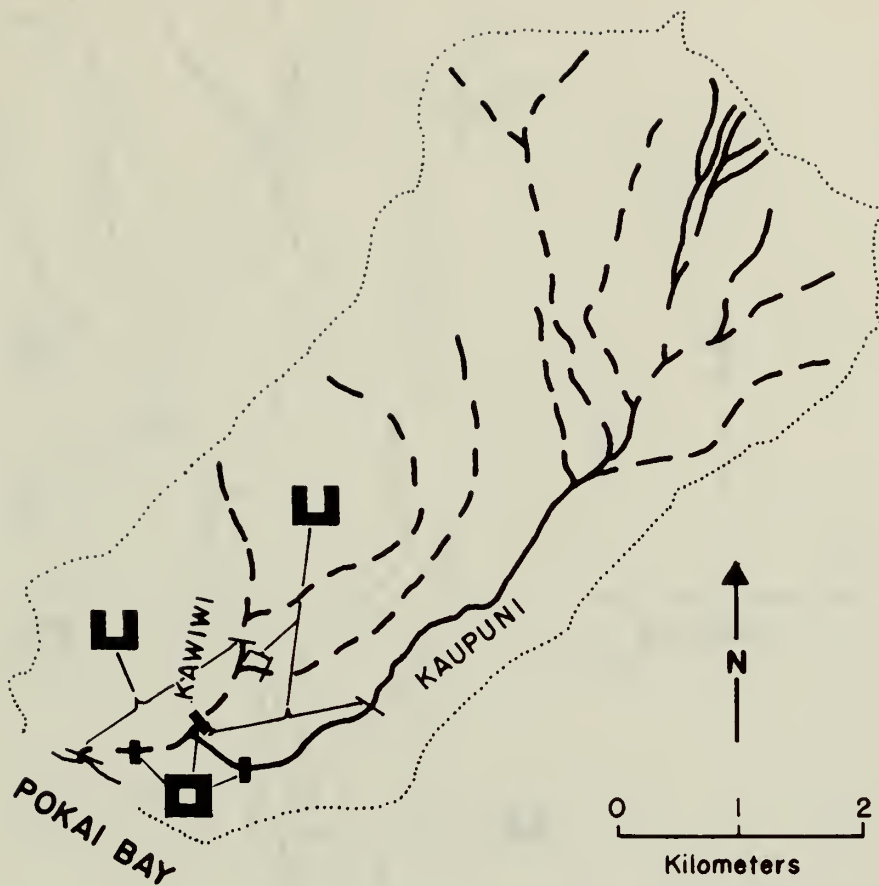


Figure B15. Kaupuni Stream, Oahu: 10% of channel length altered. Longitudinal gradient (m/km) = 61.

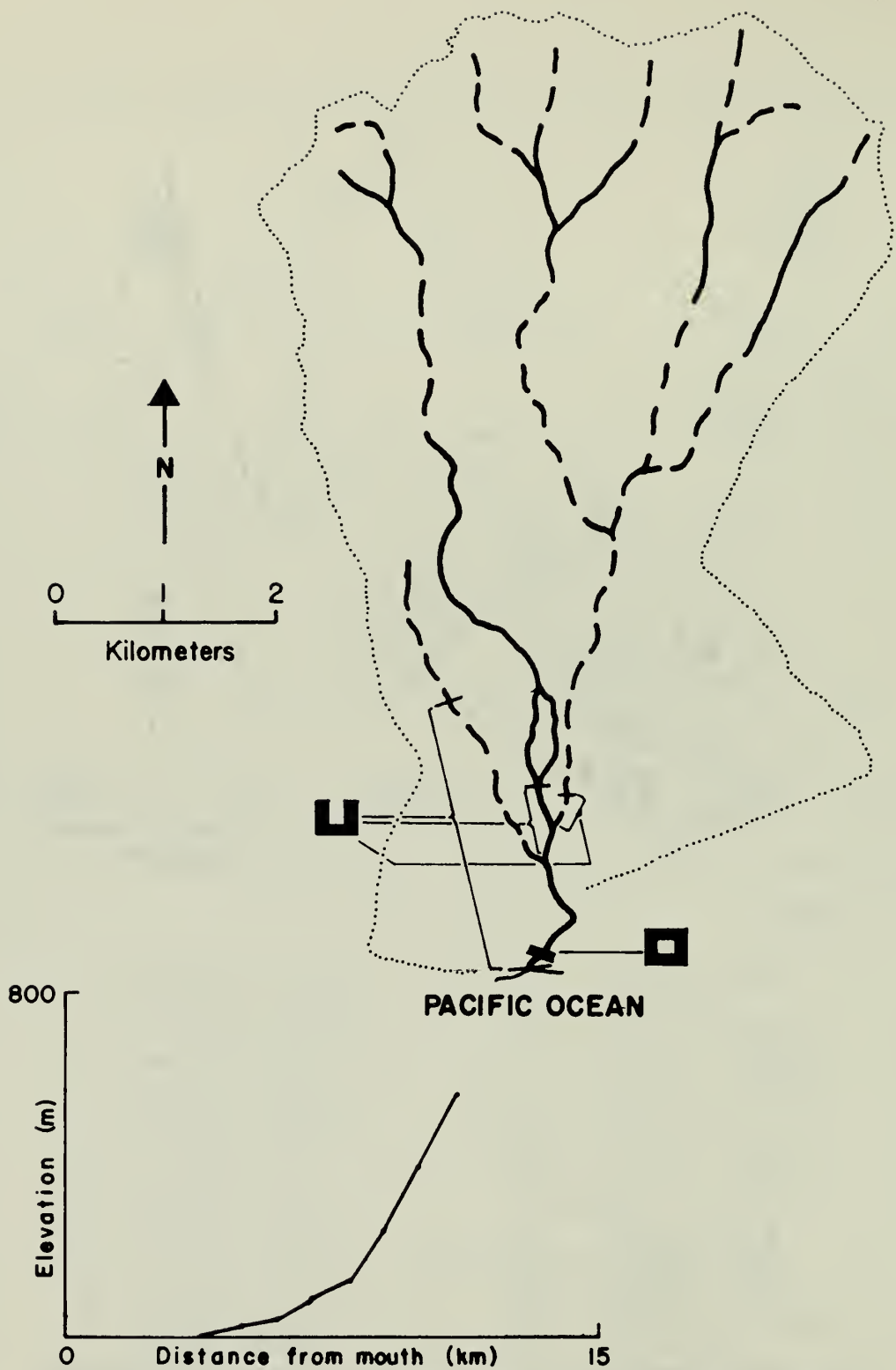


Figure B16. Mailiili Stream, Oahu: 13% of channel length altered. Longitudinal gradient (m/km) = 51.

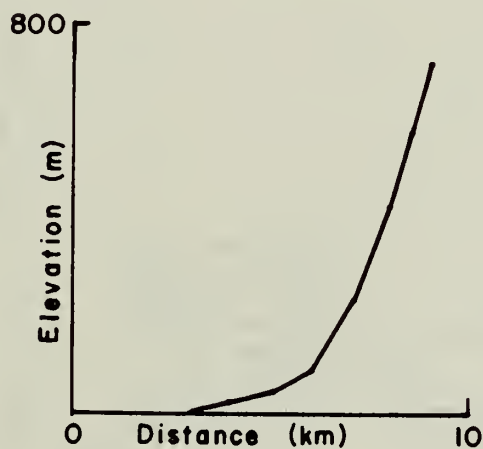
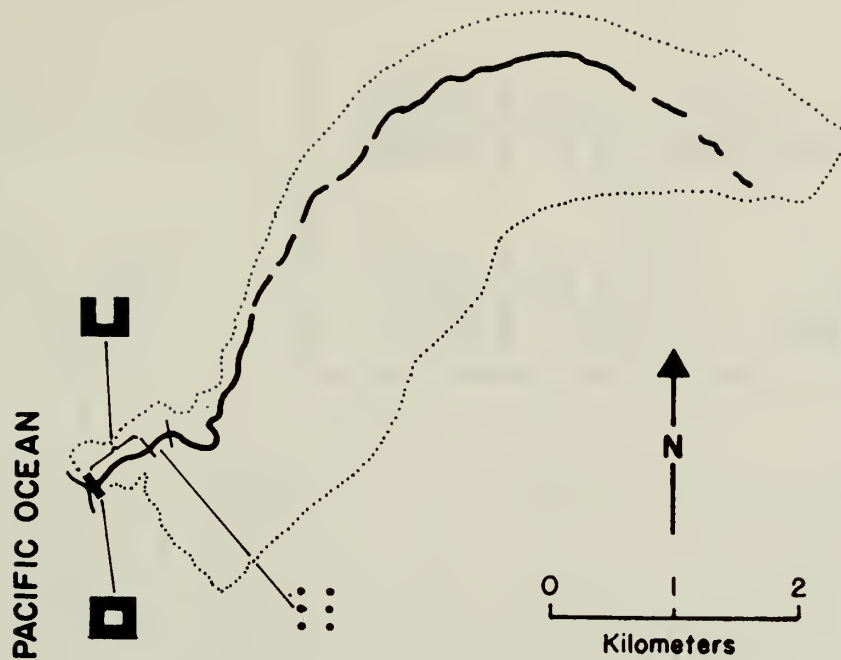


Figure B17. Ulehawa Stream, Oahu: 14% of channel length altered. Longitudinal gradient (m/km) = 86.

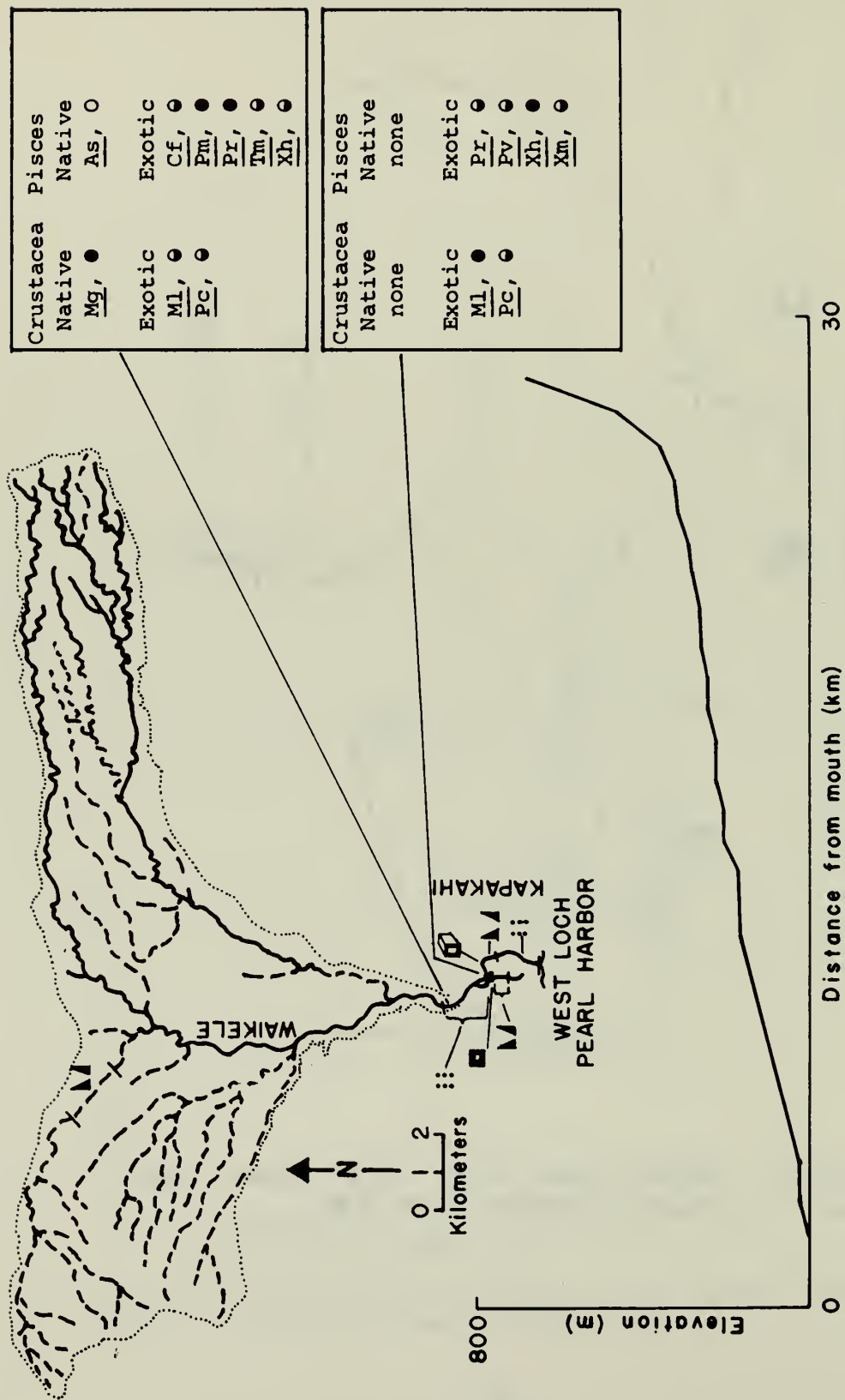


Figure B18. Waikēle Stream, Oahu: 3% of channel length altered. Longitudinal gradient (m/km) = 24.

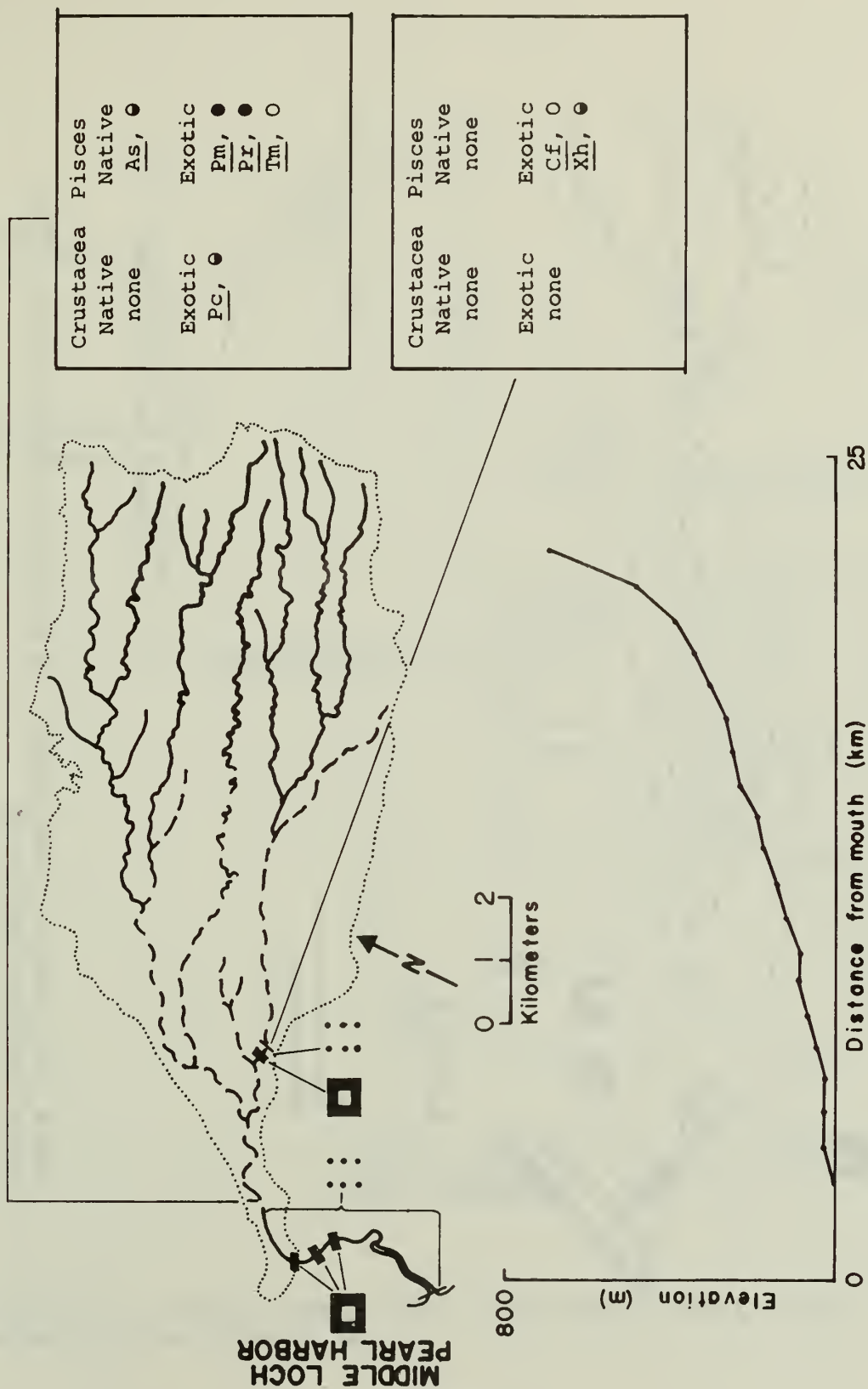


Figure B19. Waiawa Stream, Oahu: 5% of channel length altered. Longitudinal gradient (m/km) = 30.

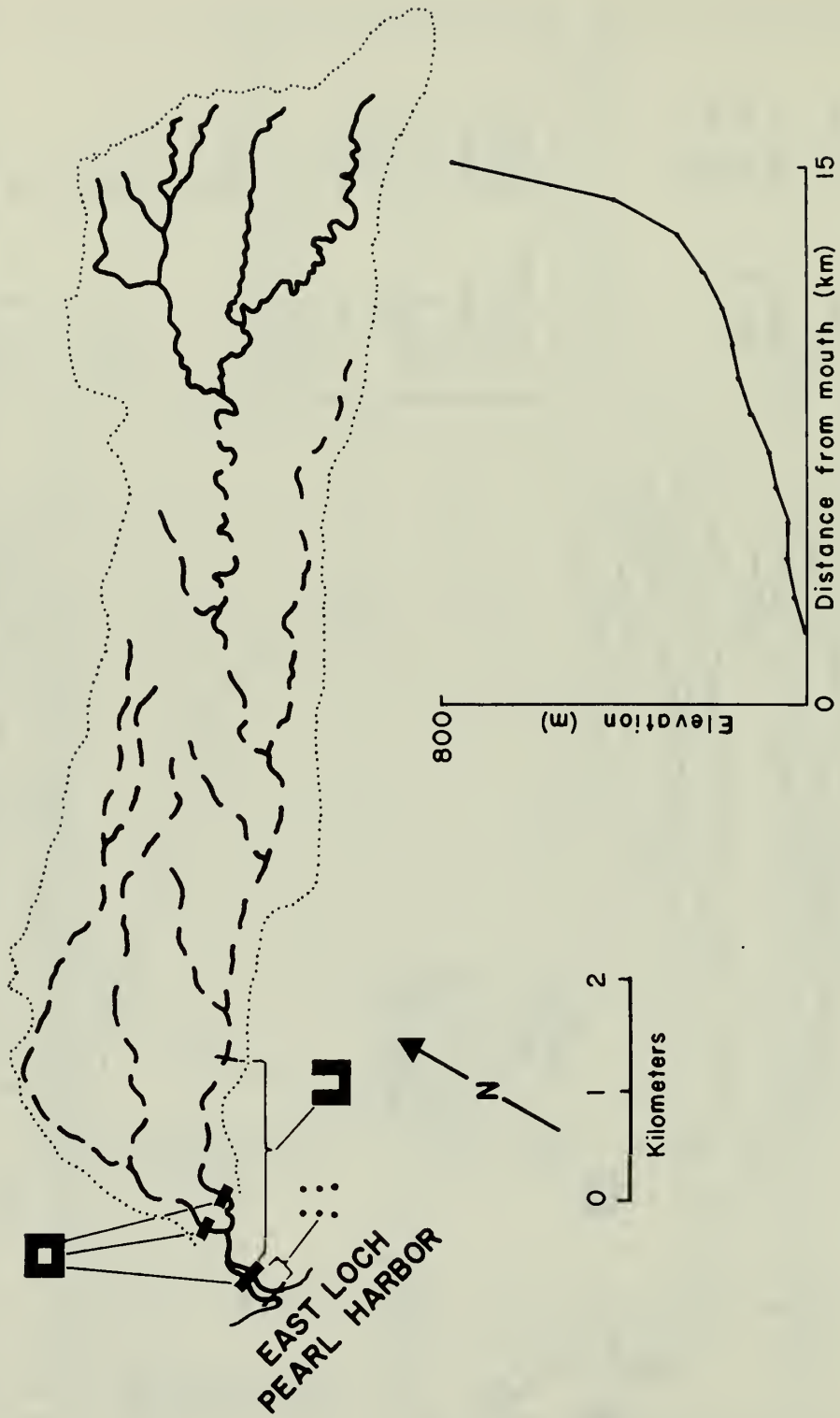


Figure B20. Waimalu Stream, Oahu: 11% of channel length altered. Longitudinal gradient (m/km) = 52.

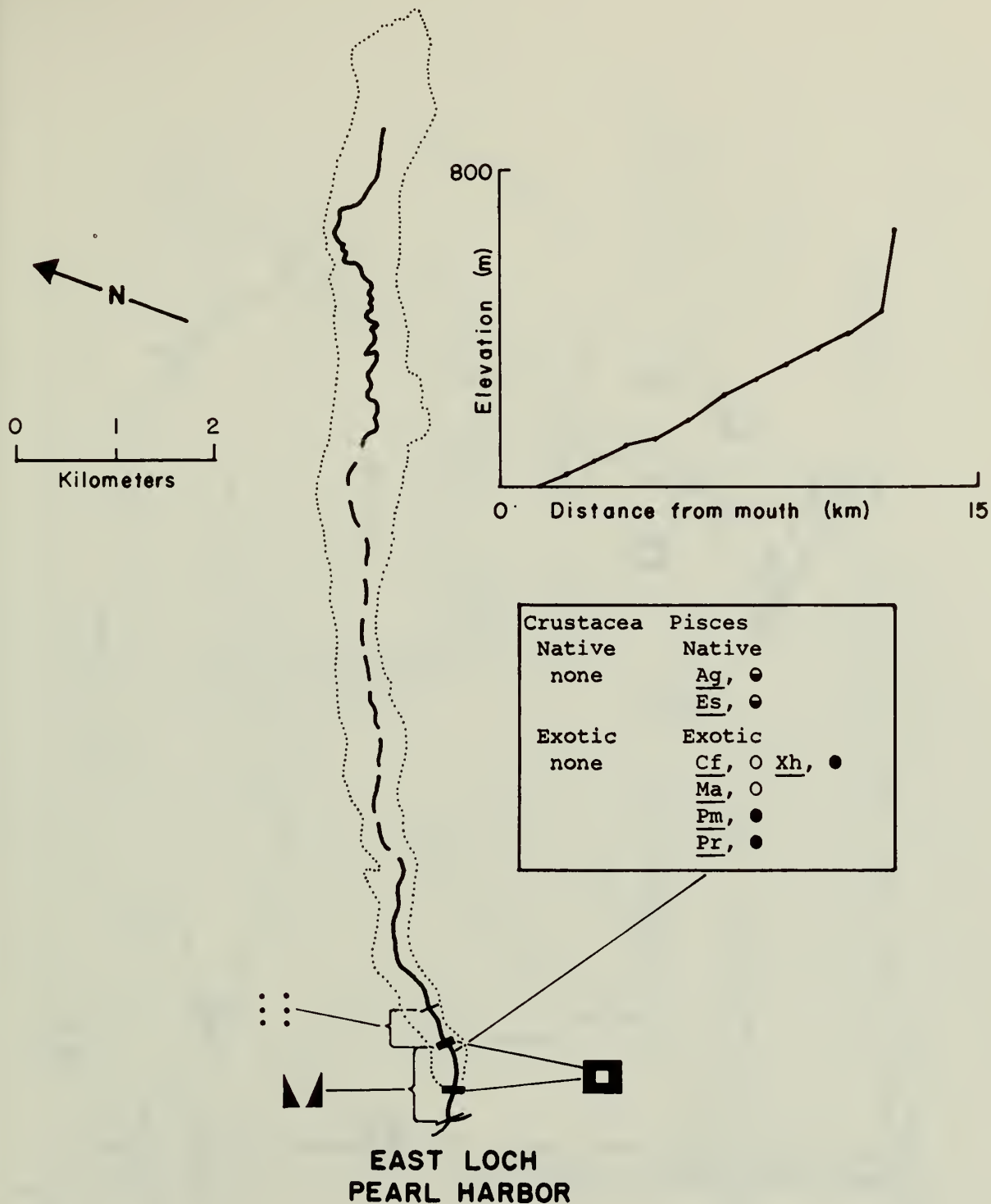


Figure B21. Kalauao Stream, Oahu: 9% of channel length altered. Longitudinal gradient (m/km) = 50.

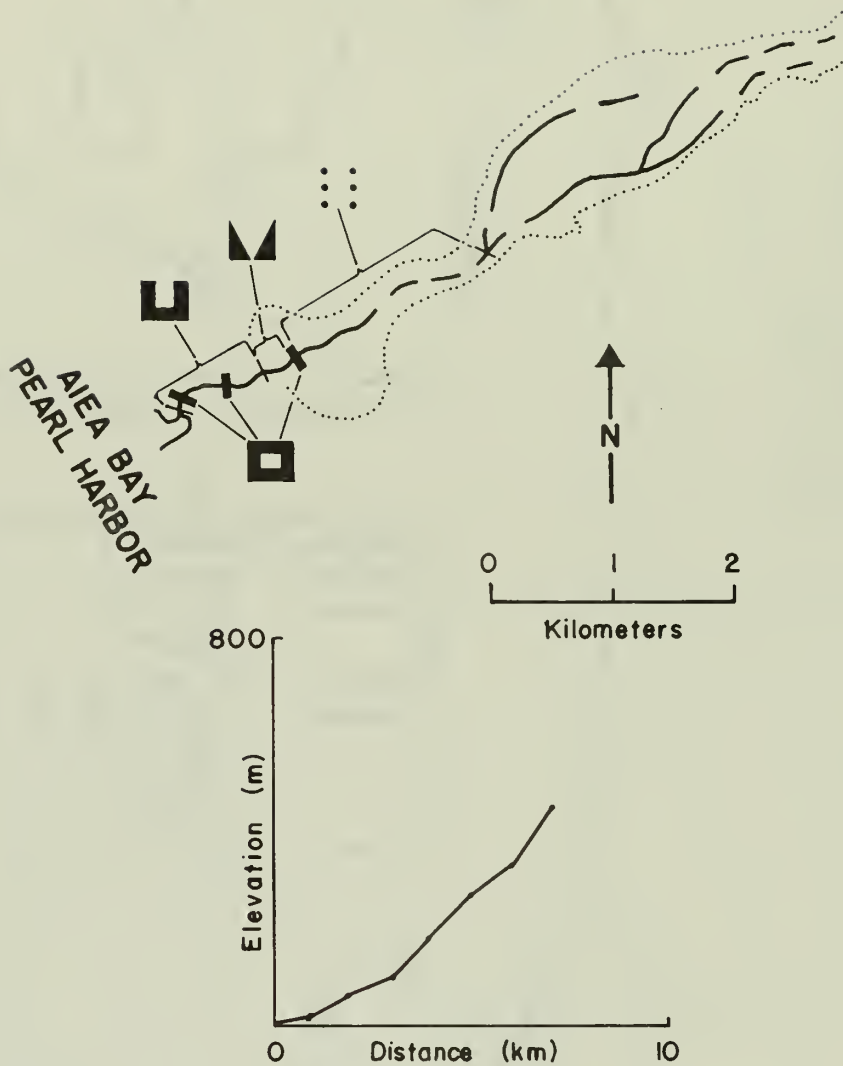


Figure B22. Aiea Stream, Oahu: 25% of channel length altered. Longitudinal gradient (m/km) = 63.

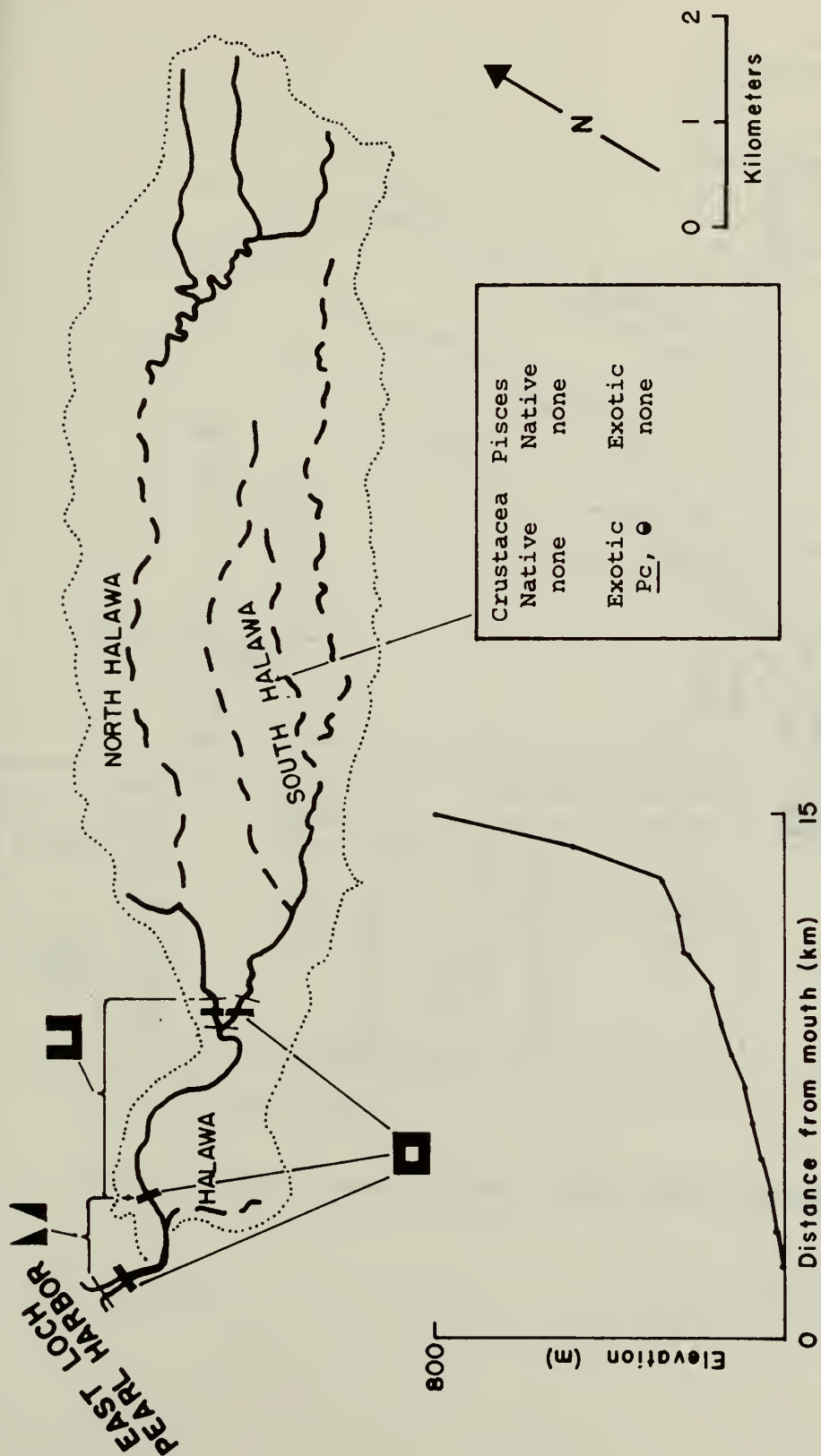


Figure B23. Halawa Stream, Oahu: 10% of channel length altered. Longitudinal gradient (m/km) = 53.

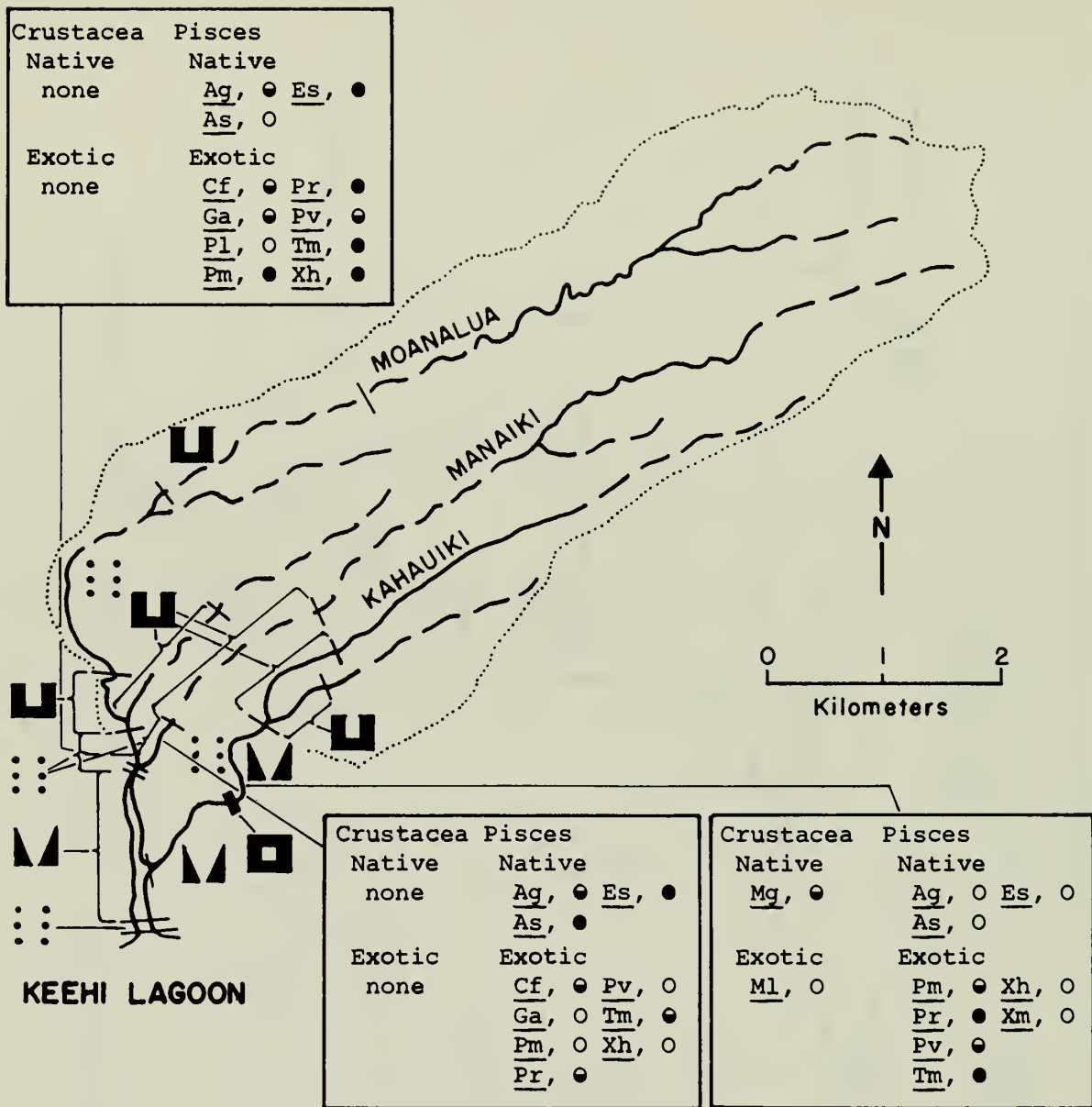


Figure B24. Moanalua Stream, Oahu: 34% of channel length altered.

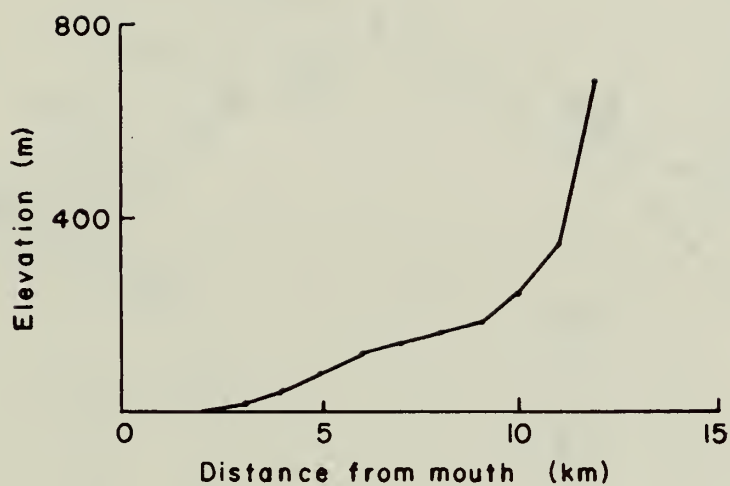


Figure B25. Profile of Moanalua Stream, Oahu. Longitudinal gradient (m/km) = 56.

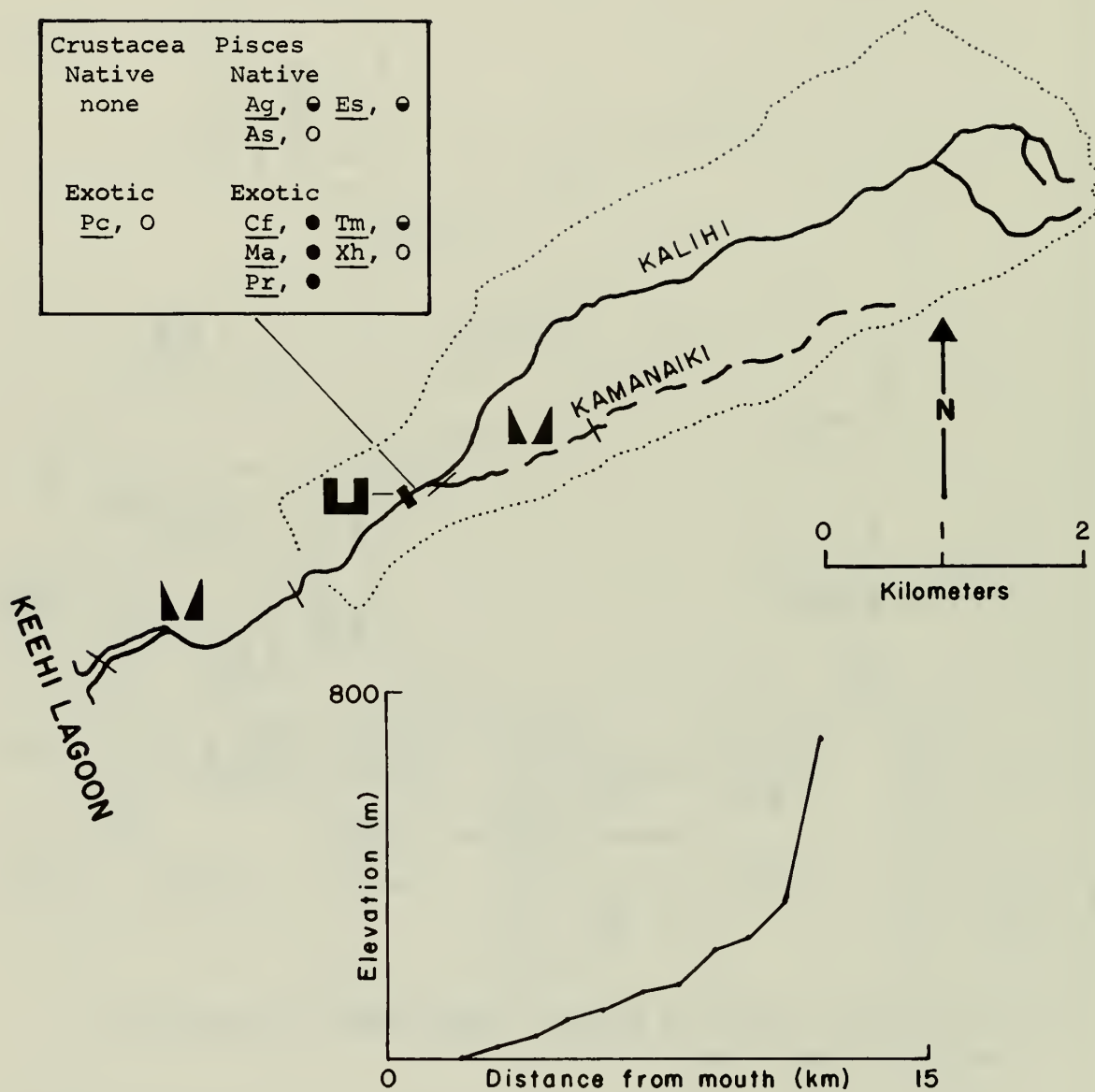


Figure B26. Kalihi Stream, Oahu: 27% of channel length altered. Longitudinal gradient (m/km) = 57.

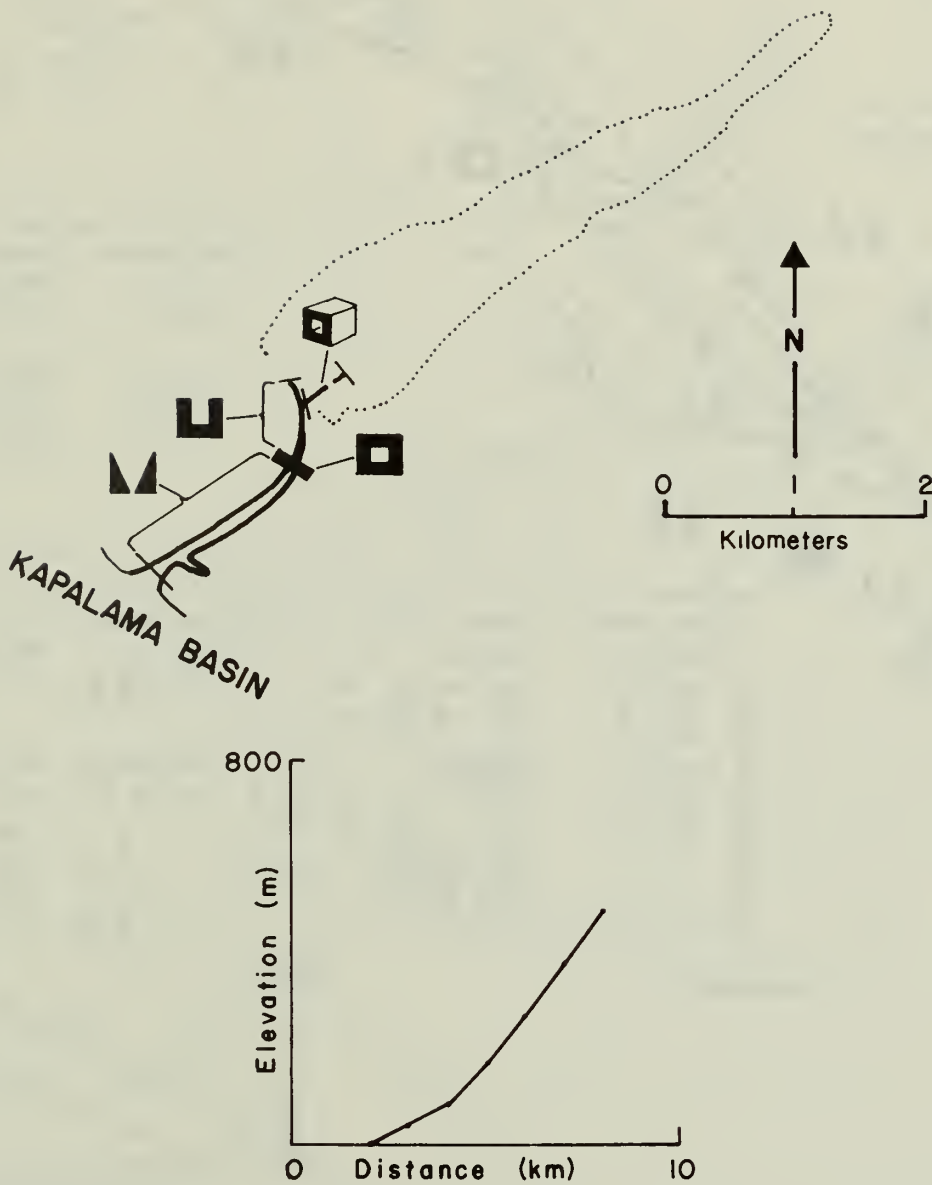


Figure B27. Kapalama Stream, Oahu: 100% of channel length altered. Longitudinal gradient (m/km) = 59.

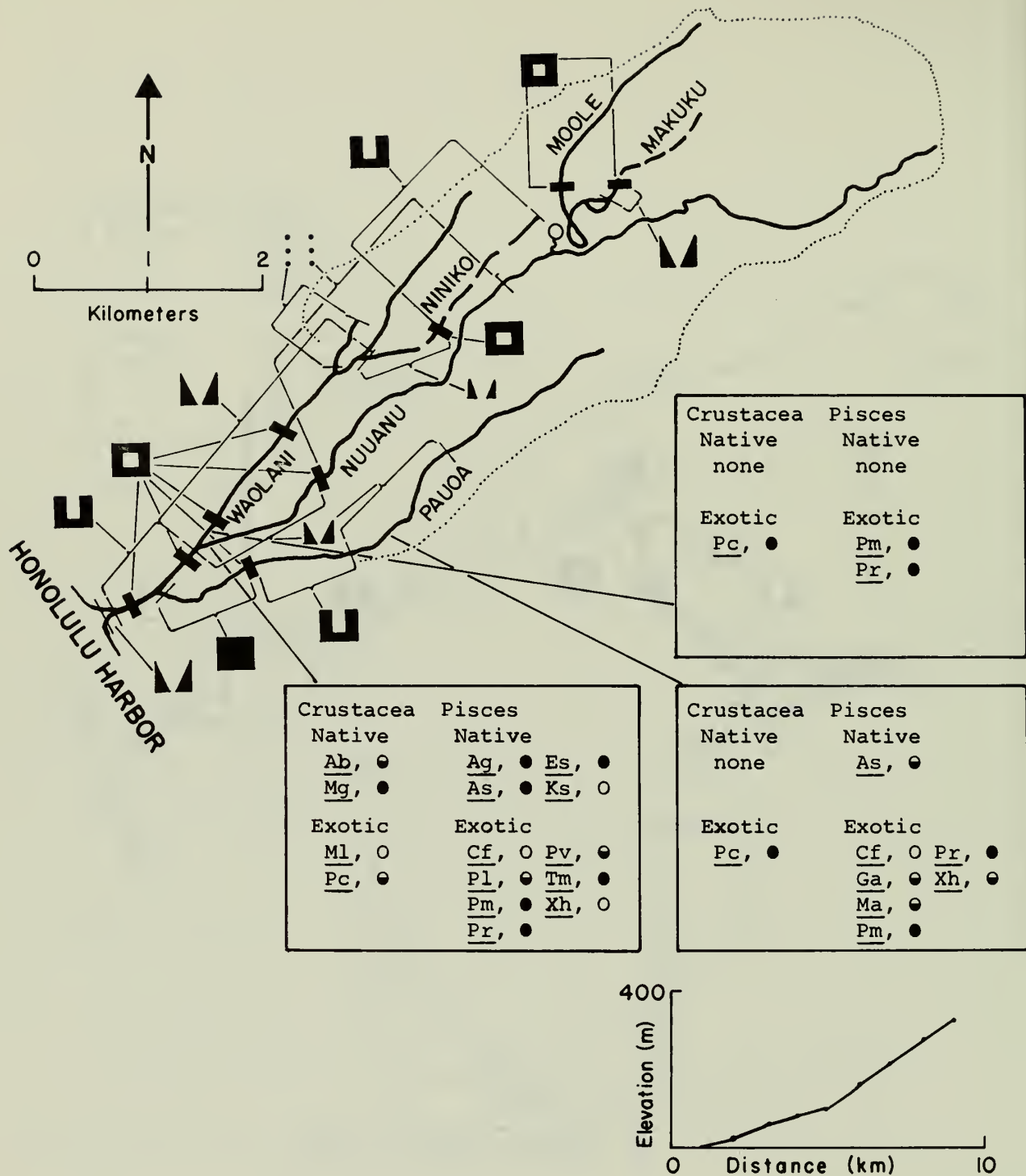


Figure B28. Nuuanu Stream, Oahu: 60% of channel length altered. Longitudinal gradient (m/km) = 35.

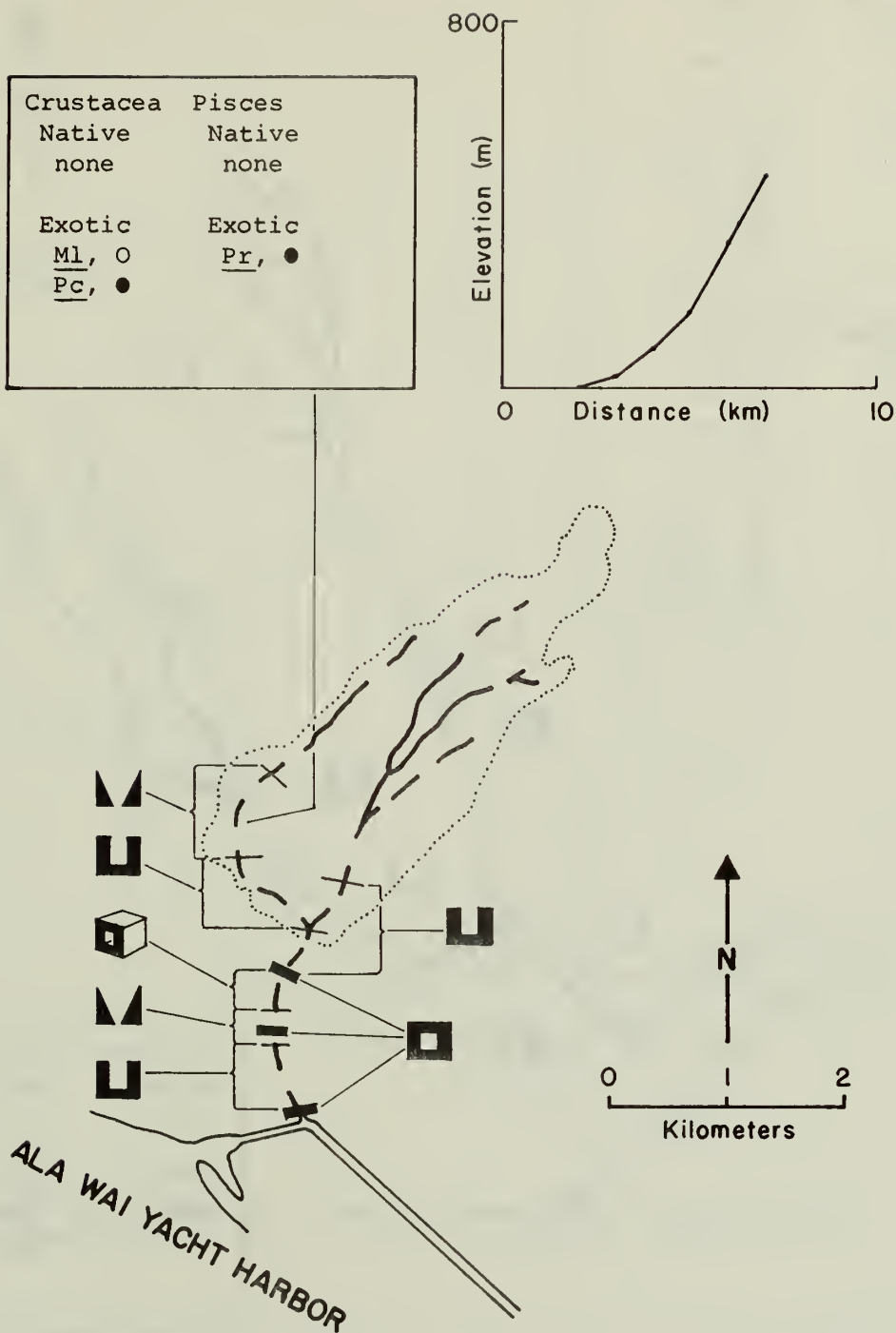


Figure B29. Makiki Stream, Oahu: 32% of channel length altered. Longitudinal gradient (m/km) = 65.

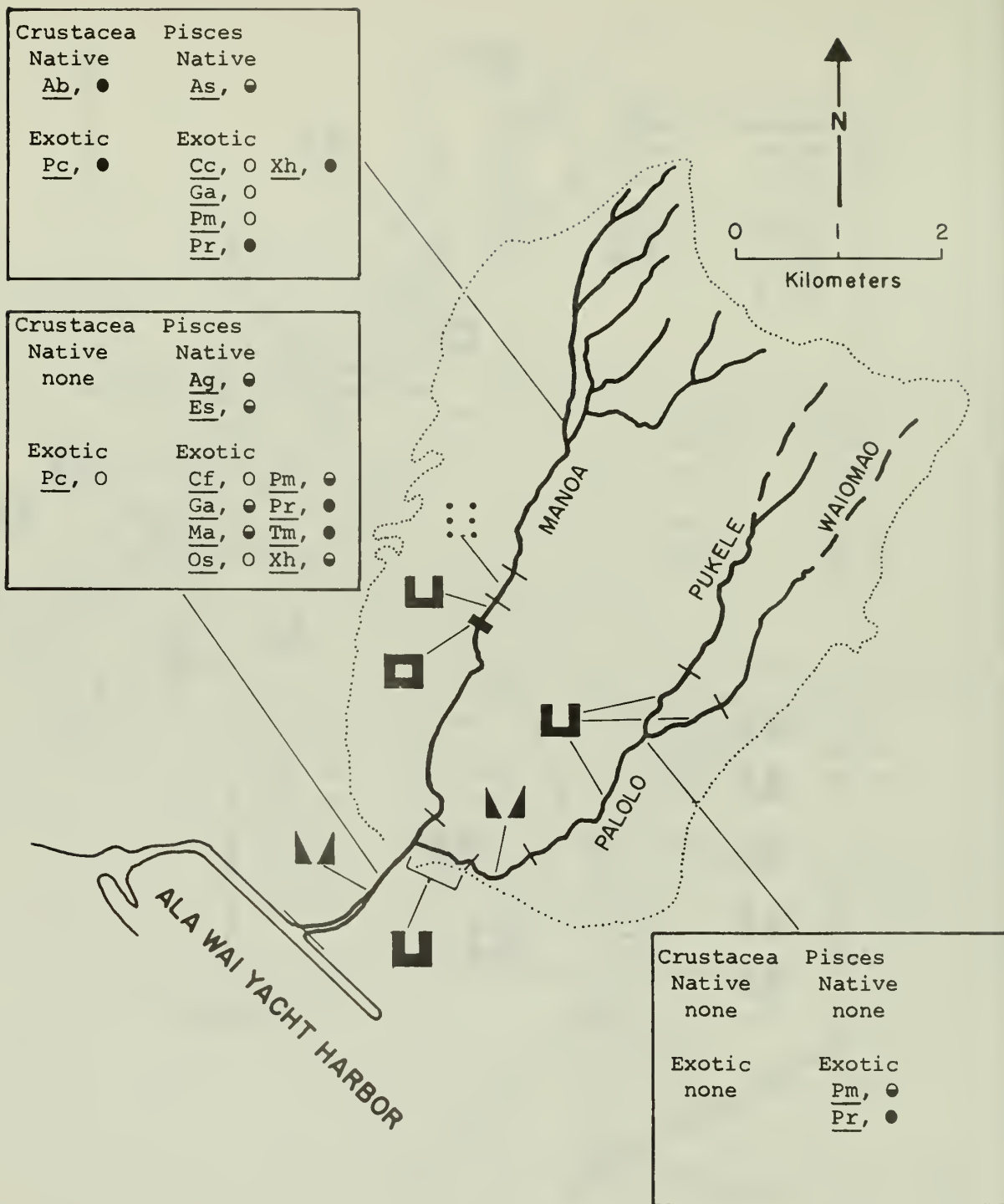


Figure B30. Manoa Stream, Oahu: 24% of channel length altered. Longitudinal gradient (m/km) = 64.

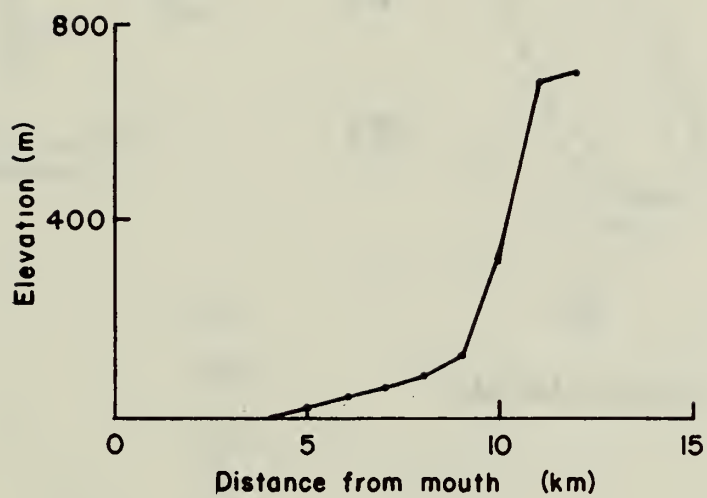


Figure B31. Profile of Manoa Stream, Oahu. Longitudinal gradient (m/km) = 64.

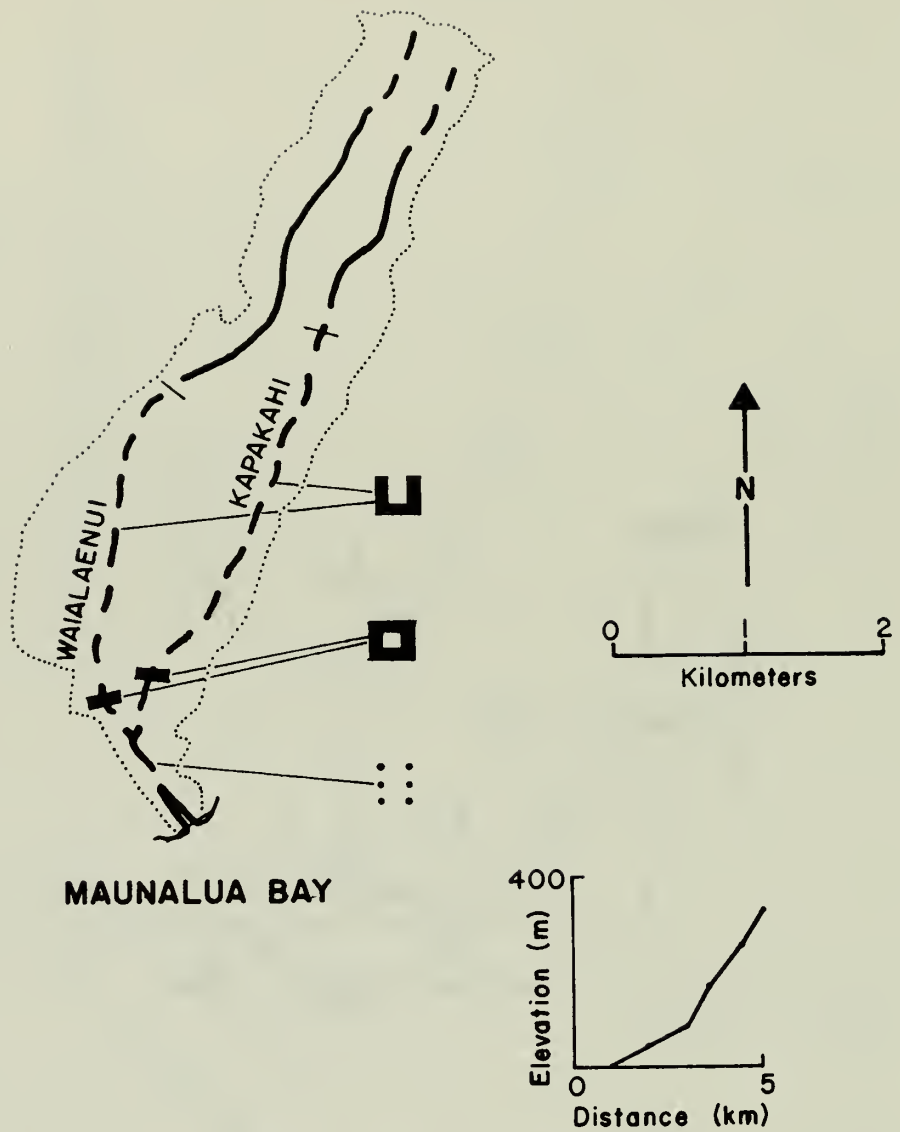


Figure B32. Waialaenui Stream, Oahu: 54% of channel length altered. Longitudinal gradient (m/km) = 54.

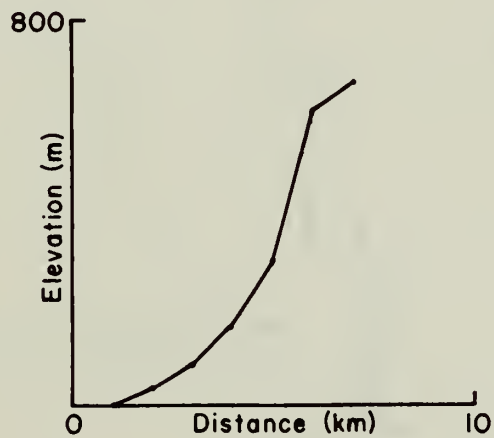
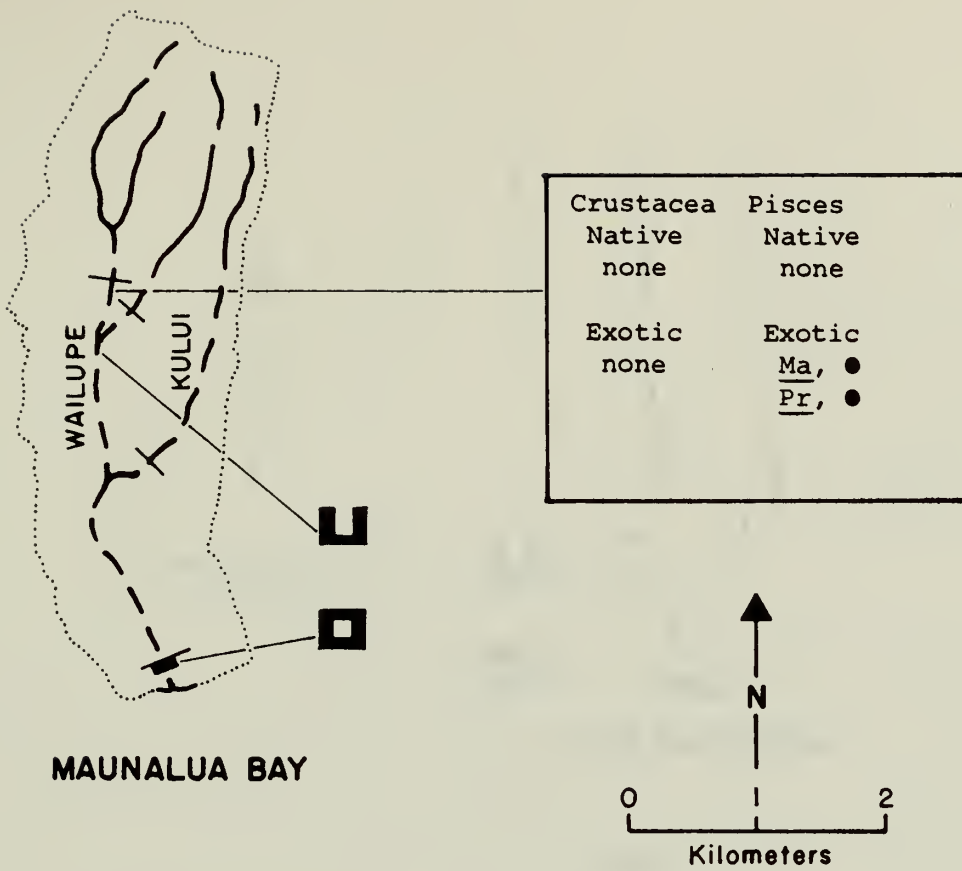


Figure B33. Wailupe Stream, Oahu: 29% of channel length altered. Longitudinal gradient (m/km) = 93.

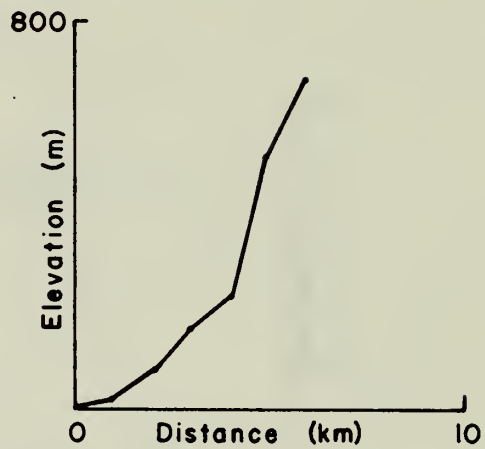
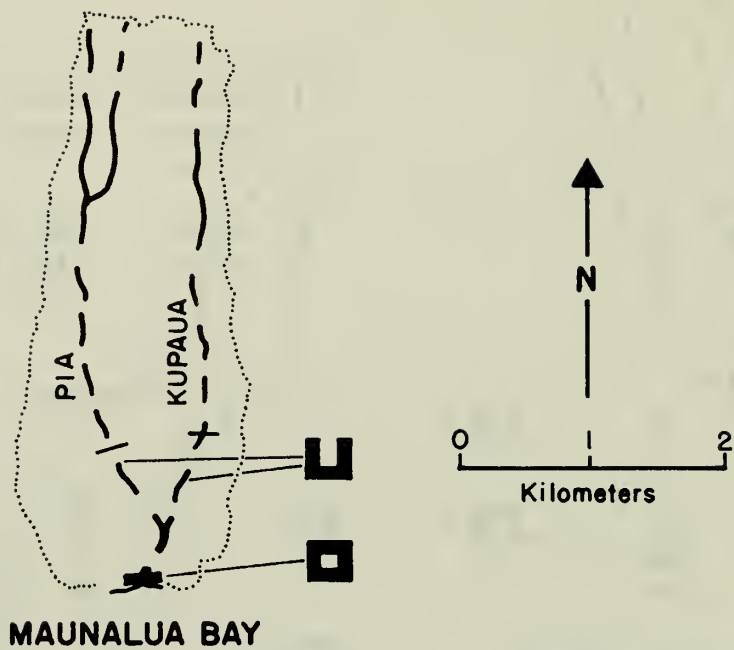


Figure B34. Pia Stream, Oahu: 21% of channel length altered. Longitudinal gradient (m/km) = 134.

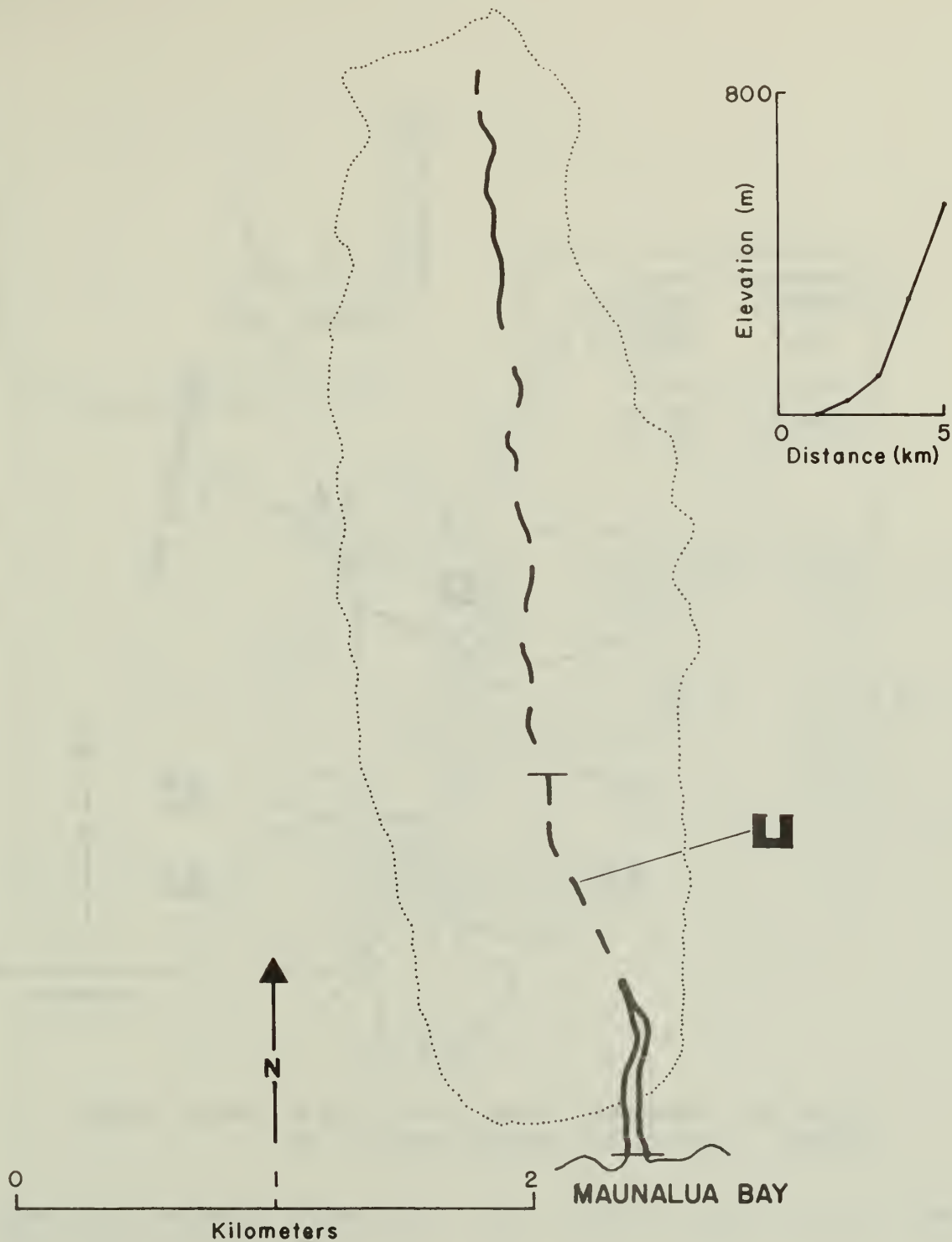


Figure B35. Kuliouou Stream, Oahu: 40% of channel length altered.
 Longitudinal gradient (m/km) = 121.

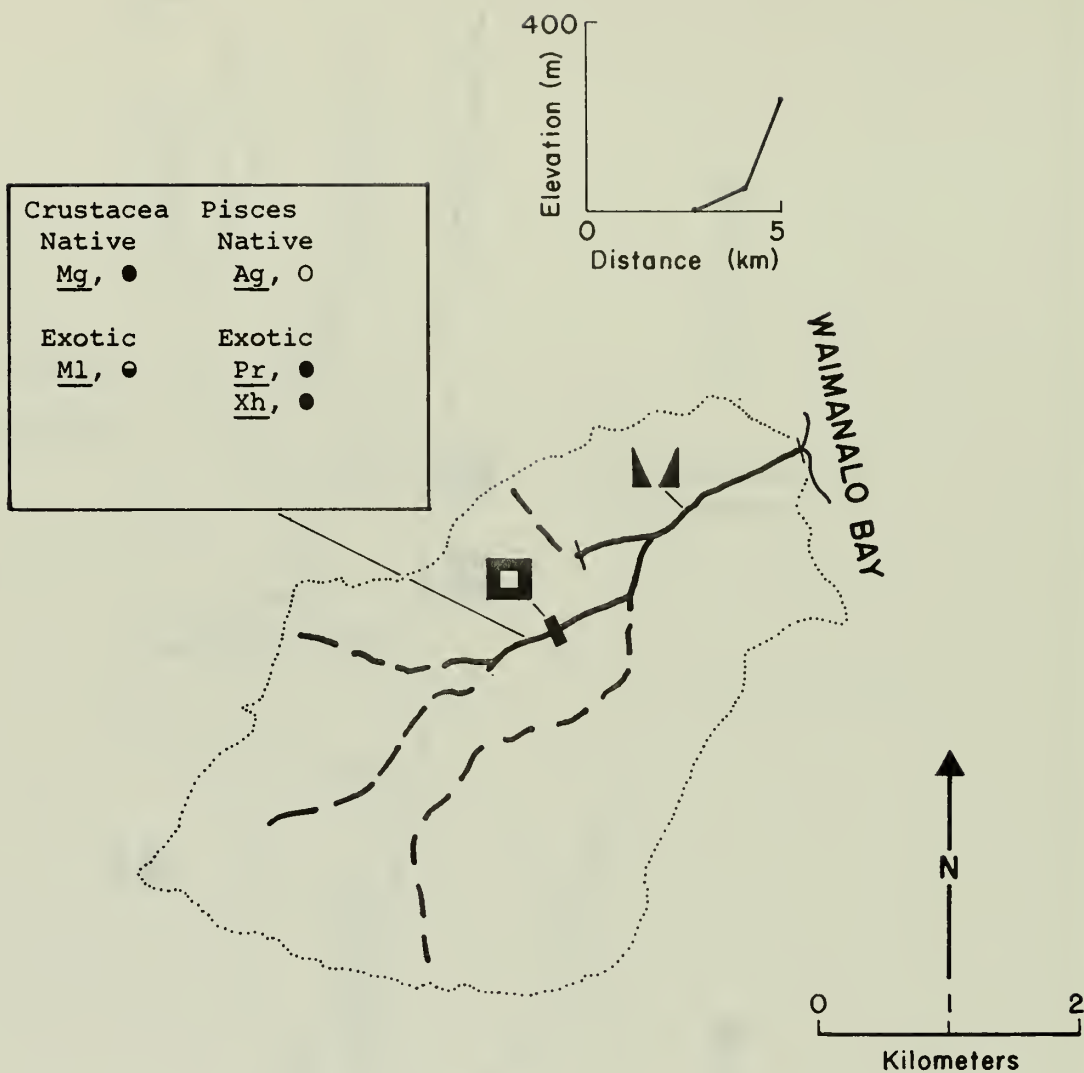


Figure B36. Waimanalo Stream, Oahu: 23% of channel length altered. Longitudinal gradient (m/km) = 44.

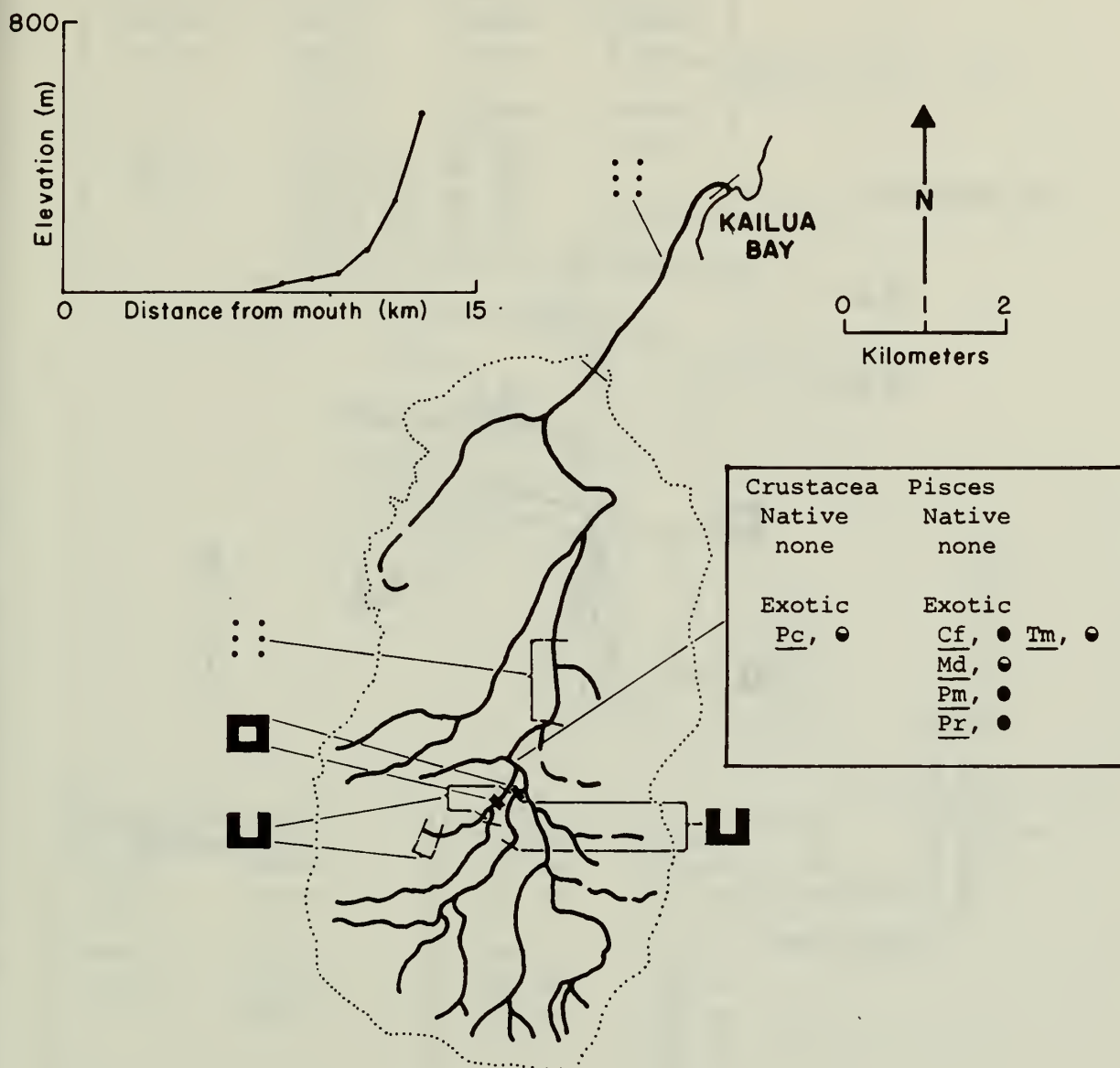


Figure B37. Maunawili Stream, Oahu: 4% of channel length altered. Longitudinal gradient (m/km) = 43.

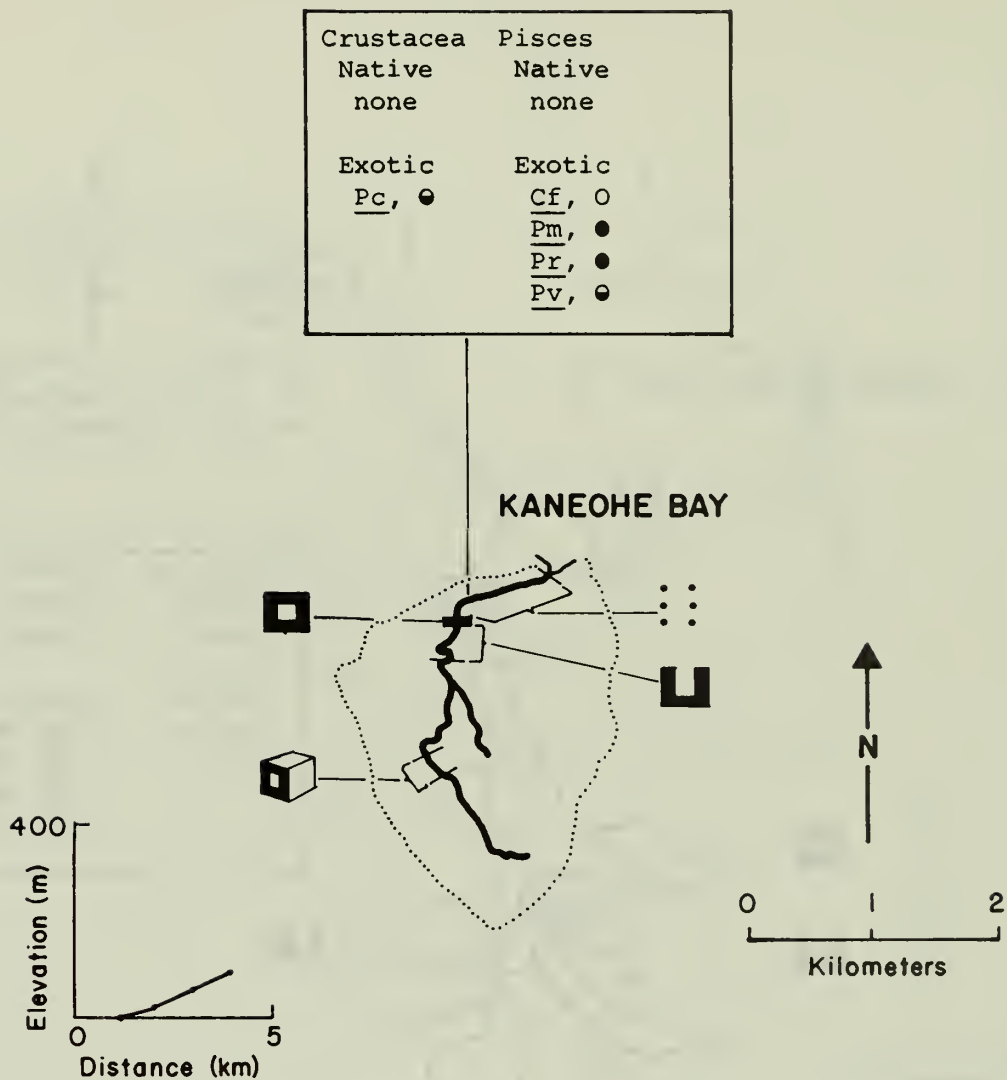


Figure B38. Kawa Stream, Oahu: 36% of channel length altered. Longitudinal gradient (m/km) = 24.

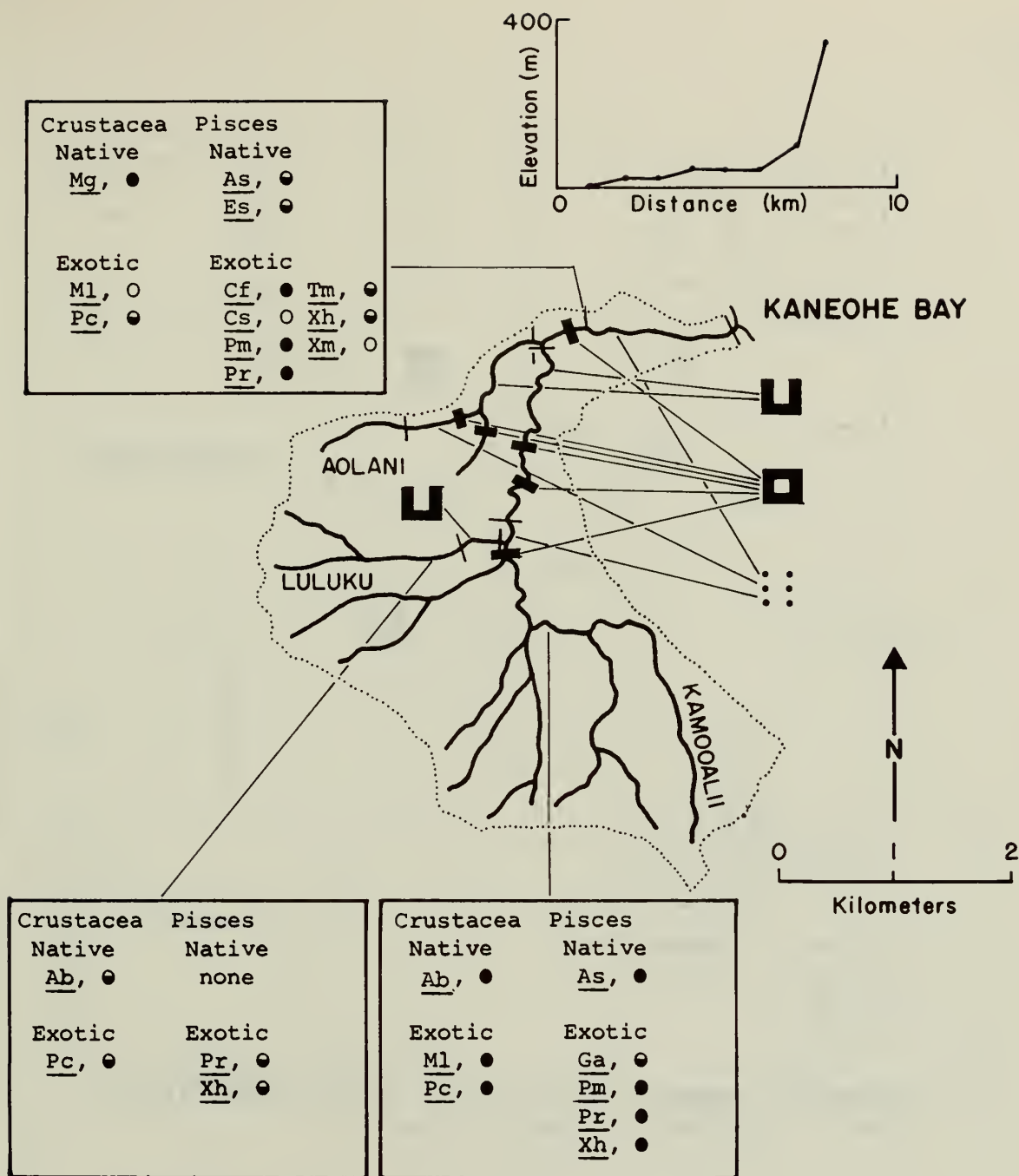


Figure B39. Kaneohe Stream, Oahu: 25% of channel length altered. Longitudinal gradient (m/km) = 67.

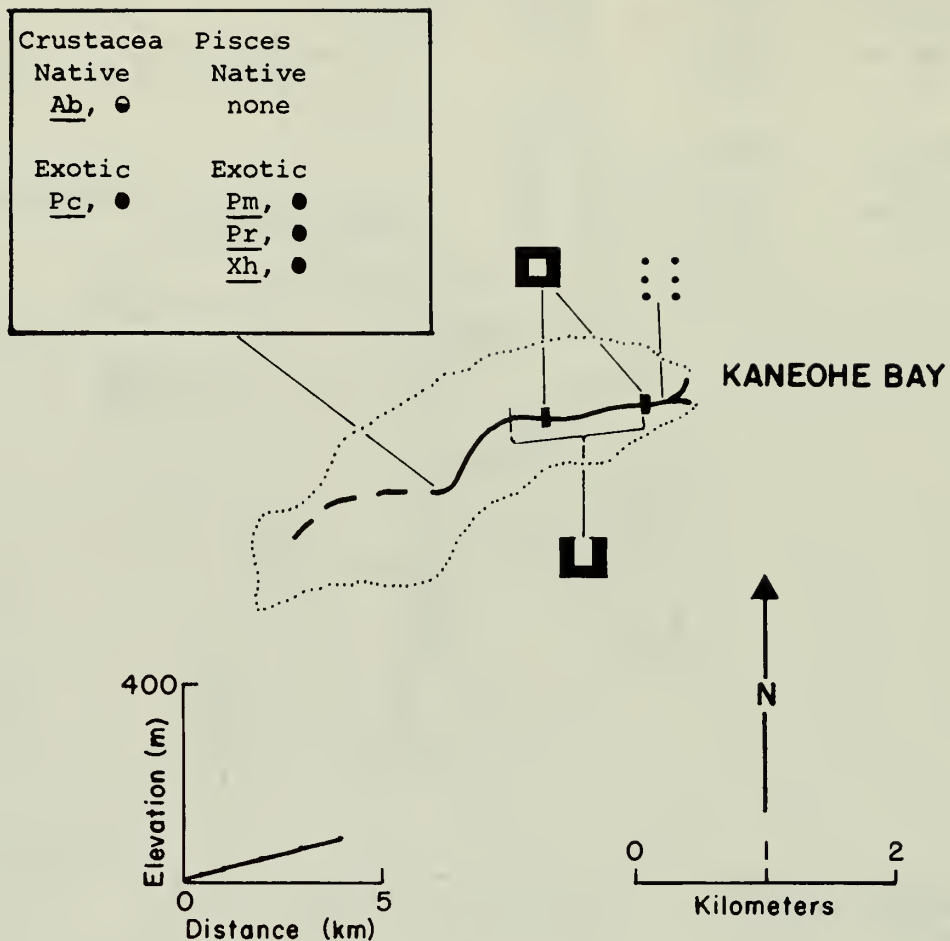


Figure B40. Keaahala Stream, Oahu: 38% of channel length altered. Longitudinal gradient (m/km) = 23.

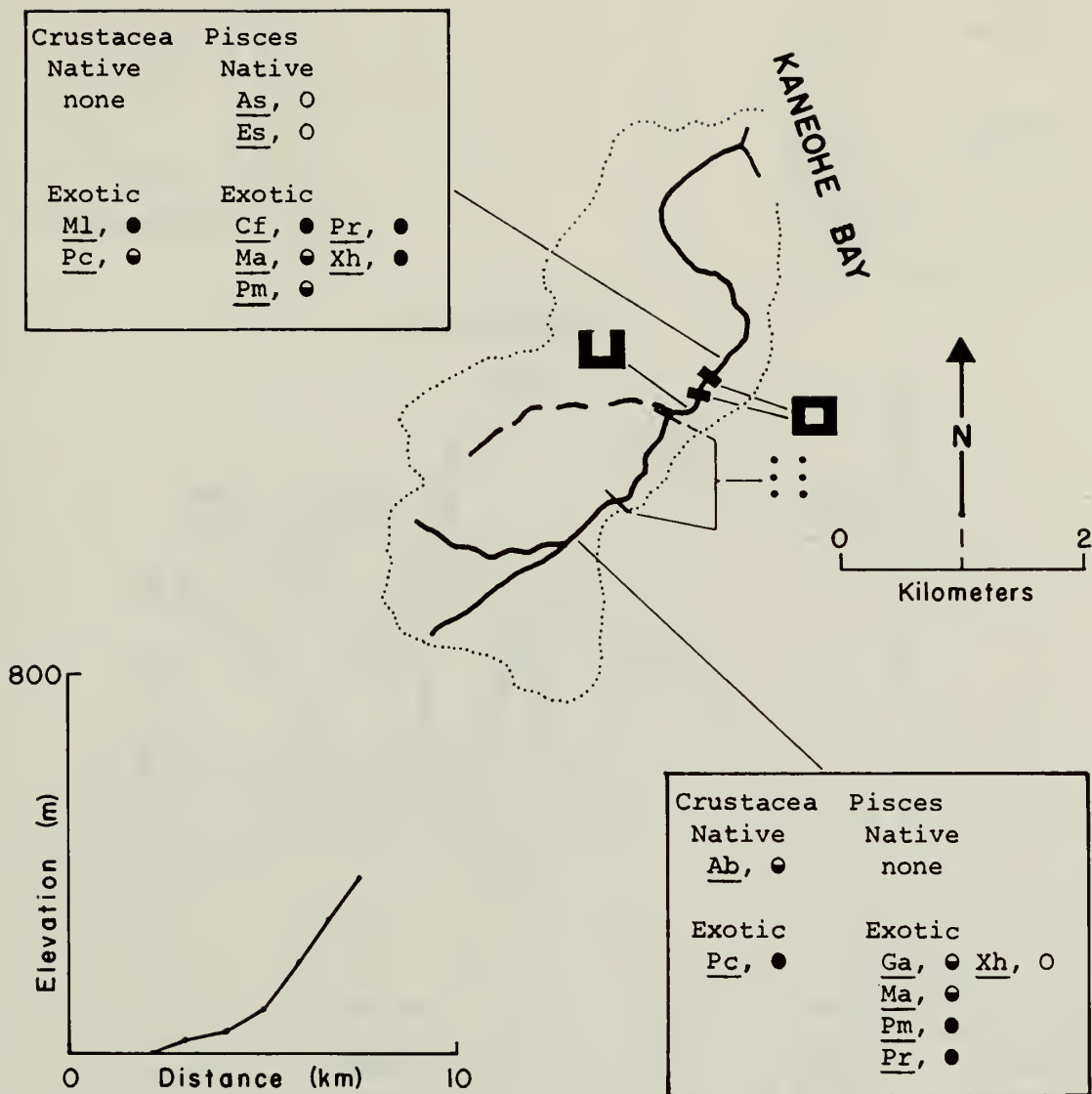
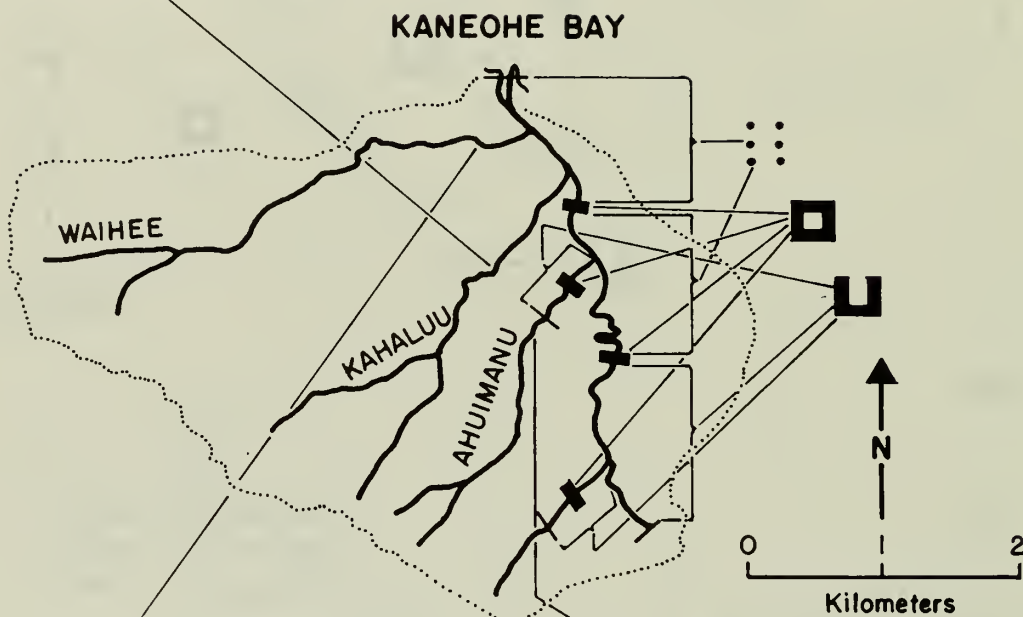
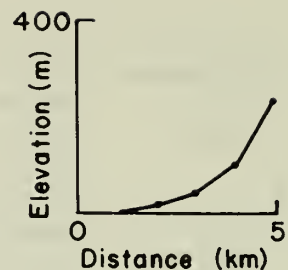


Figure B41. Heeia Stream, Oahu: 14% of channel length altered. Longitudinal gradient (m/km) = 48.

Crustacea	Pisces
Native	Native
none	<u>Es</u> , ●
Exotic	Exotic
<u>Pc</u> , ●	<u>Pm</u> , ●
	<u>Pr</u> , ●
	<u>Tm</u> , ○
	<u>Kh</u> , ●

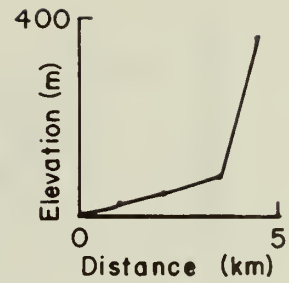


Crustacea	Pisces
Native	Native
<u>Mg</u> , ●	<u>Ag</u> , ● <u>Es</u> , ●
	<u>As</u> , ○ <u>Ks</u> , ○
Exotic	Exotic
<u>Ml</u> , ●	<u>Pr</u> , ○
<u>Pc</u> , ●	<u>Kh</u> , ●

Crustacea	Pisces
Native	Native
none	<u>Ag</u> , ● <u>Es</u> , ○
	<u>As</u> , ●
Exotic	Exotic
<u>Ml</u> , ●	<u>Cf</u> , ● <u>Tm</u> , ●
<u>Pc</u> , ●	<u>Pm</u> , ● <u>Kh</u> , ●
	<u>Pr</u> , ●
	<u>Pv</u> , ●

Figure B42. Kahaluu Stream, Oahu: 14% of channel length altered. Longitudinal gradient (m/km) = 52.

Crustacea	Pisces
Native	Native
<u>Mg</u> , ●	<u>Ag</u> , ○ <u>Es</u> , ●
	<u>As</u> , ○
Exotic	Exotic
<u>Ml</u> , ●	<u>Pr</u> , ●
	<u>Xh</u> , ●



Crustacea	Pisces
Native	Native
<u>Ab</u> , ●	none
Exotic	Exotic
<u>Ml</u> , ○	<u>Ga</u> , ●
<u>Pc</u> , ●	<u>Pm</u> , ●
	<u>Pr</u> , ●
	<u>Xh</u> , ○



Figure B43. Kaalaea Stream, Oahu: 3% of channel length altered. Longitudinal gradient (m/km) = 88.

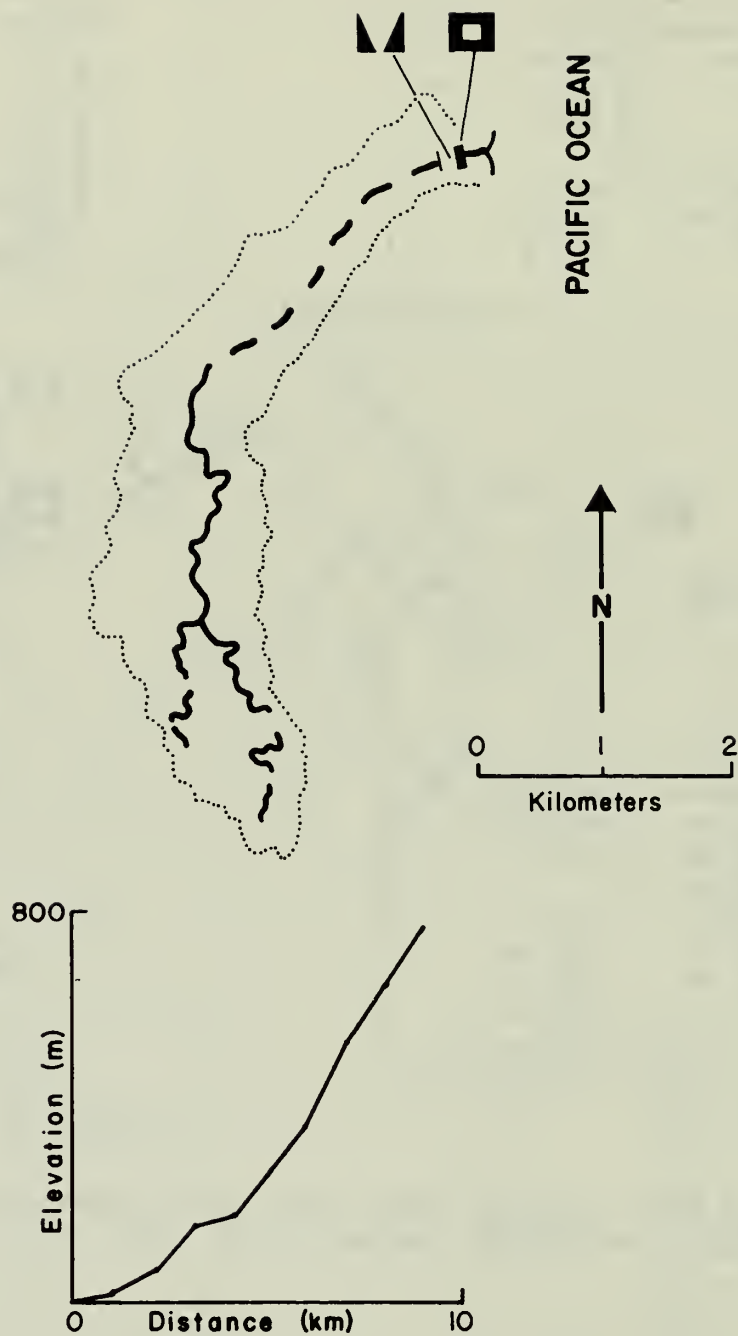


Figure B44. Kaipapau Stream, Oahu: 2% of channel length altered. Longitudinal gradient (m/km) = 86.

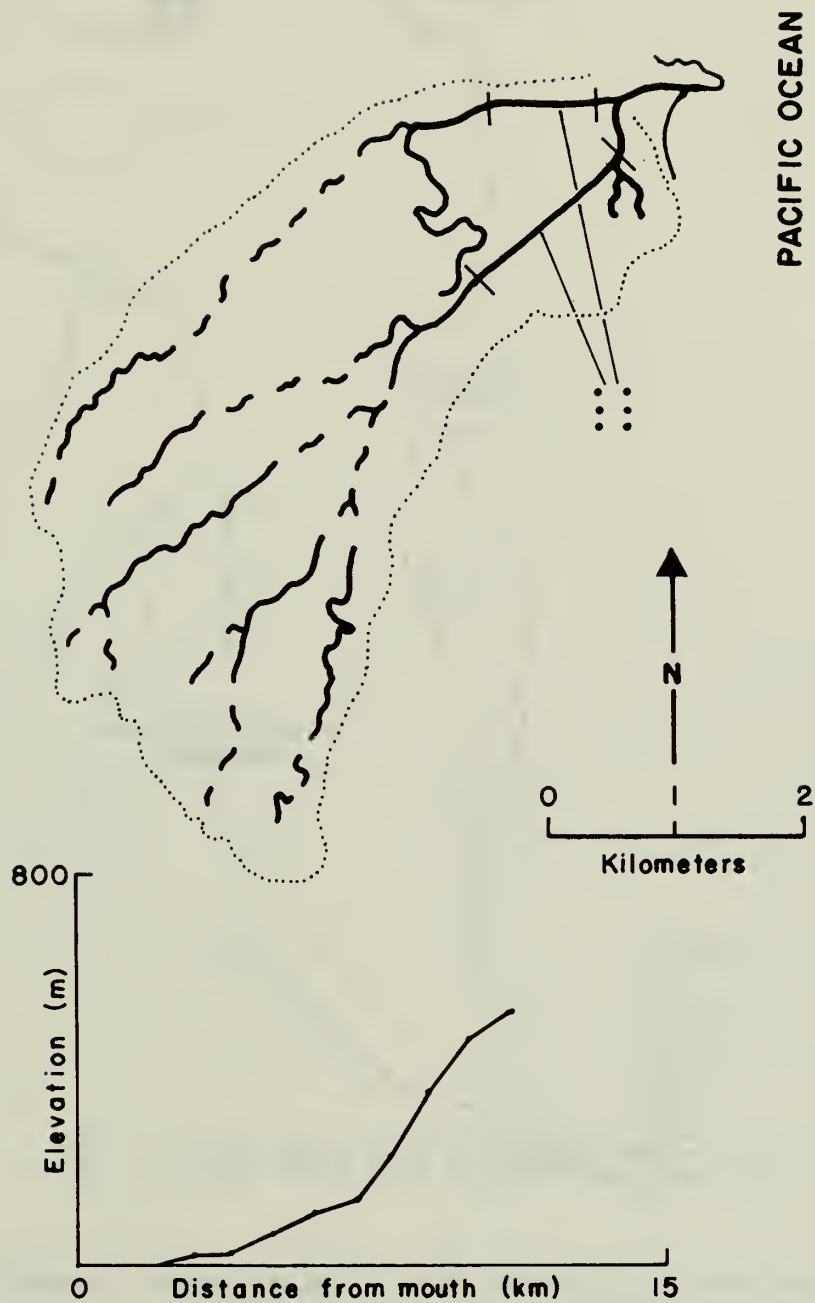


Figure B45. Malaekahana Stream, Oahu: 8% of channel length altered. Longitudinal gradient (m/km) = 50.

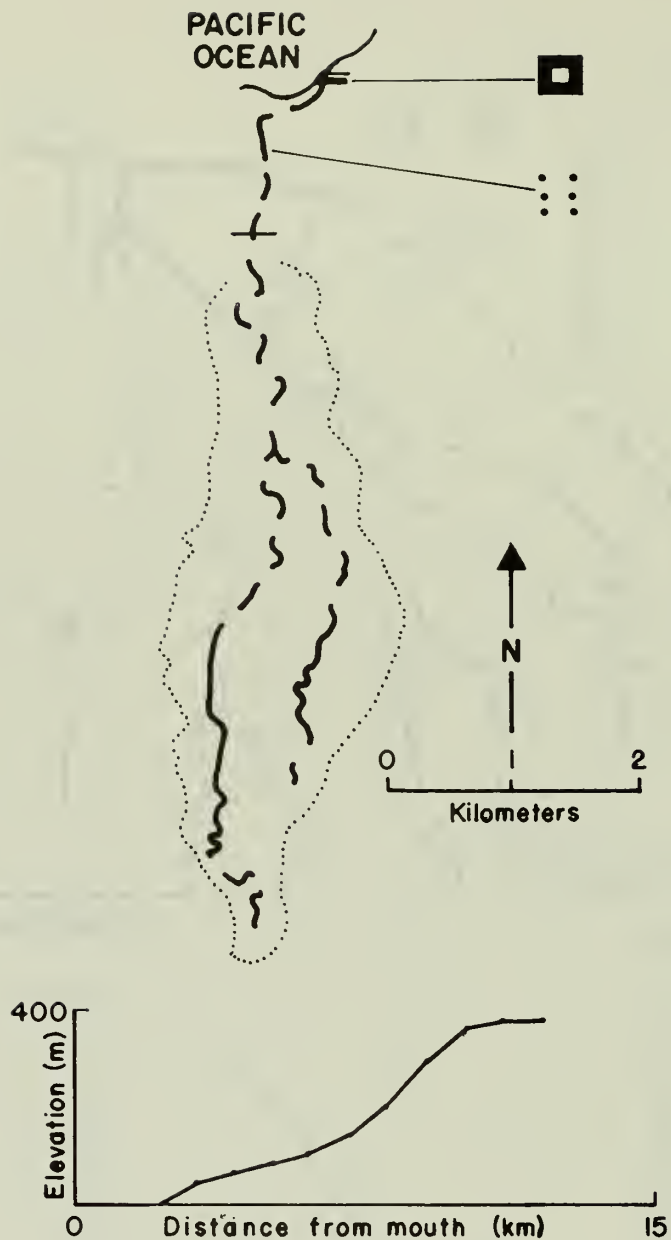


Figure B46. Oio Stream, Oahu: 20% of channel length altered. Longitudinal gradient (m/km) = 37.

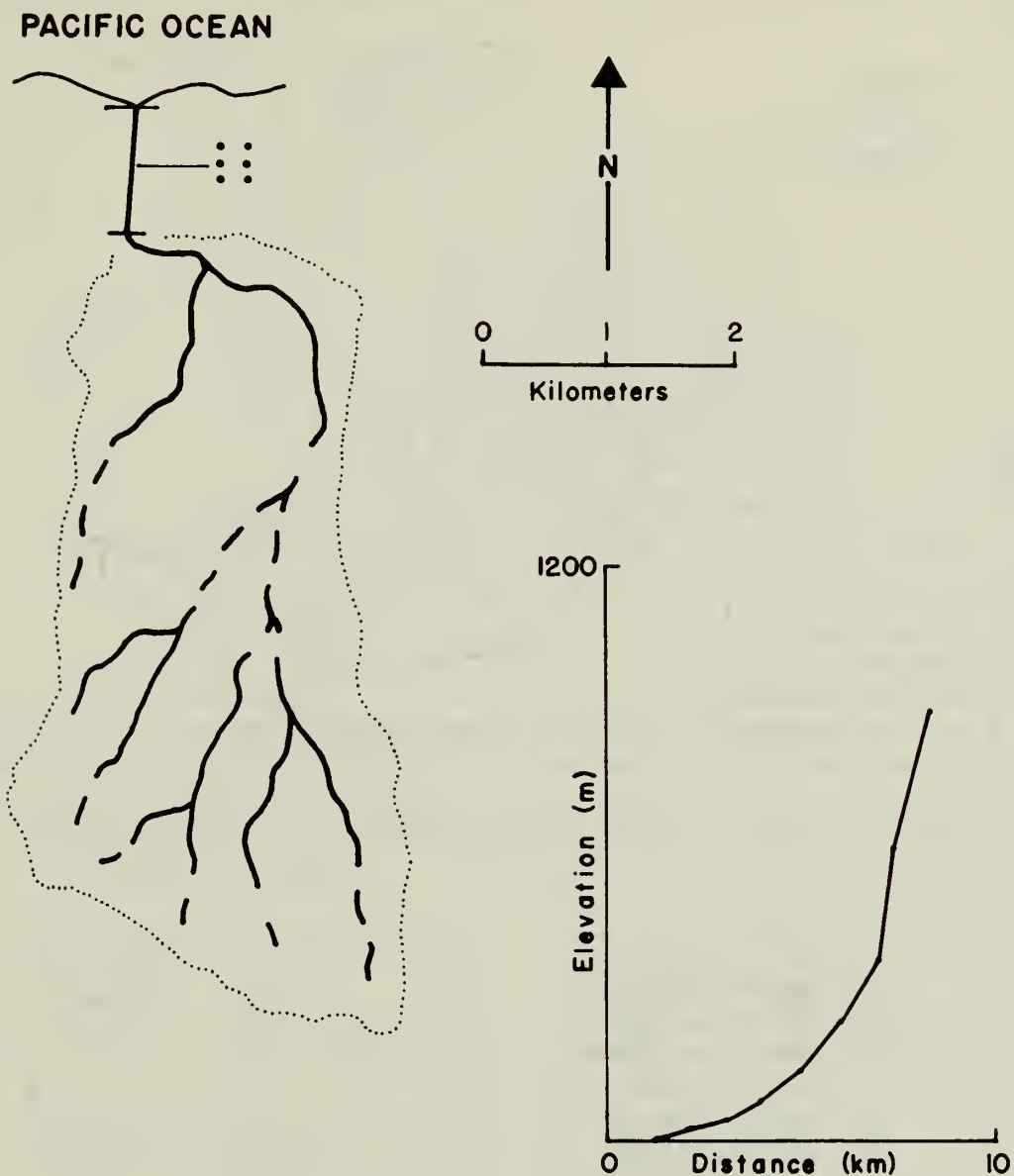


Figure B47. Makaleha Stream, Oahu: 6% of channel length altered. Longitudinal gradient (m/km) = 105.

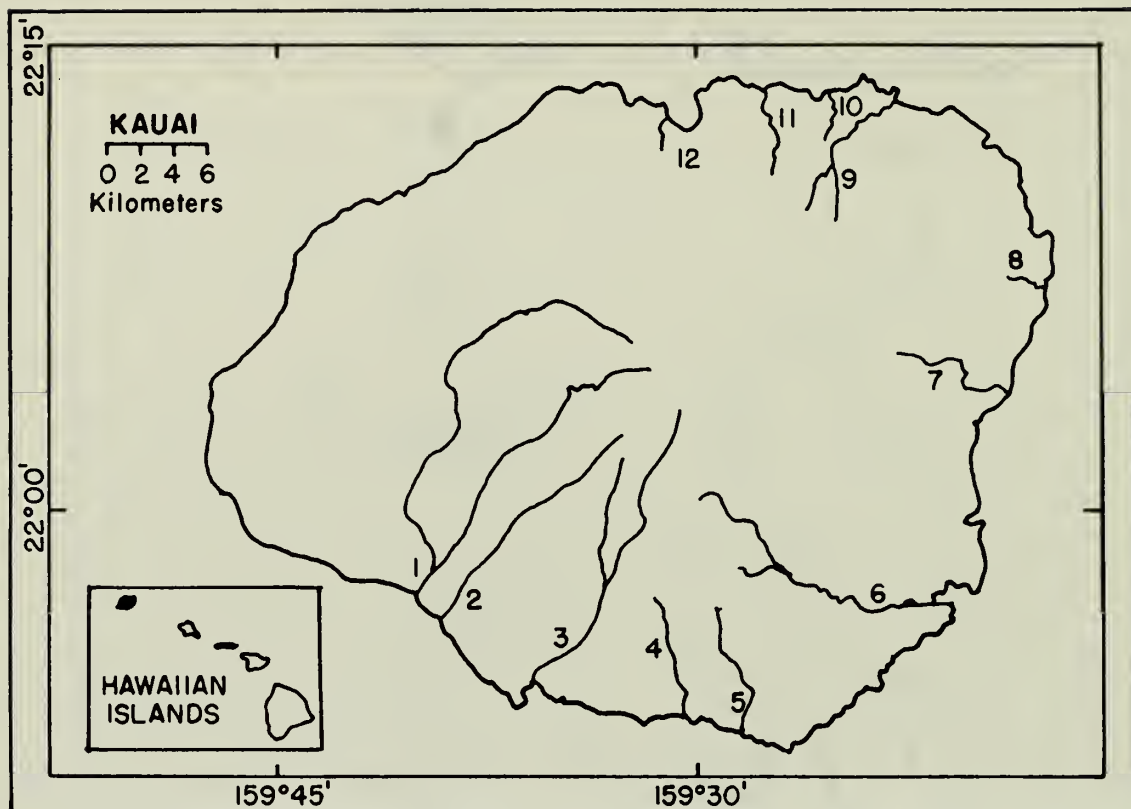


Figure B48. Locator map for the 12 Kauai streams having modified channels.

Legend:

1. Waimea River
2. Waipao Stream
3. Hanapepe Stream
4. Lawai Stream
5. Waikomo Stream
6. Huleia Stream
7. Konohiki Stream
8. Kumukumu Stream
9. Kilauea Stream
10. Puukumu Stream
11. Anini Stream
12. Waikoko Stream

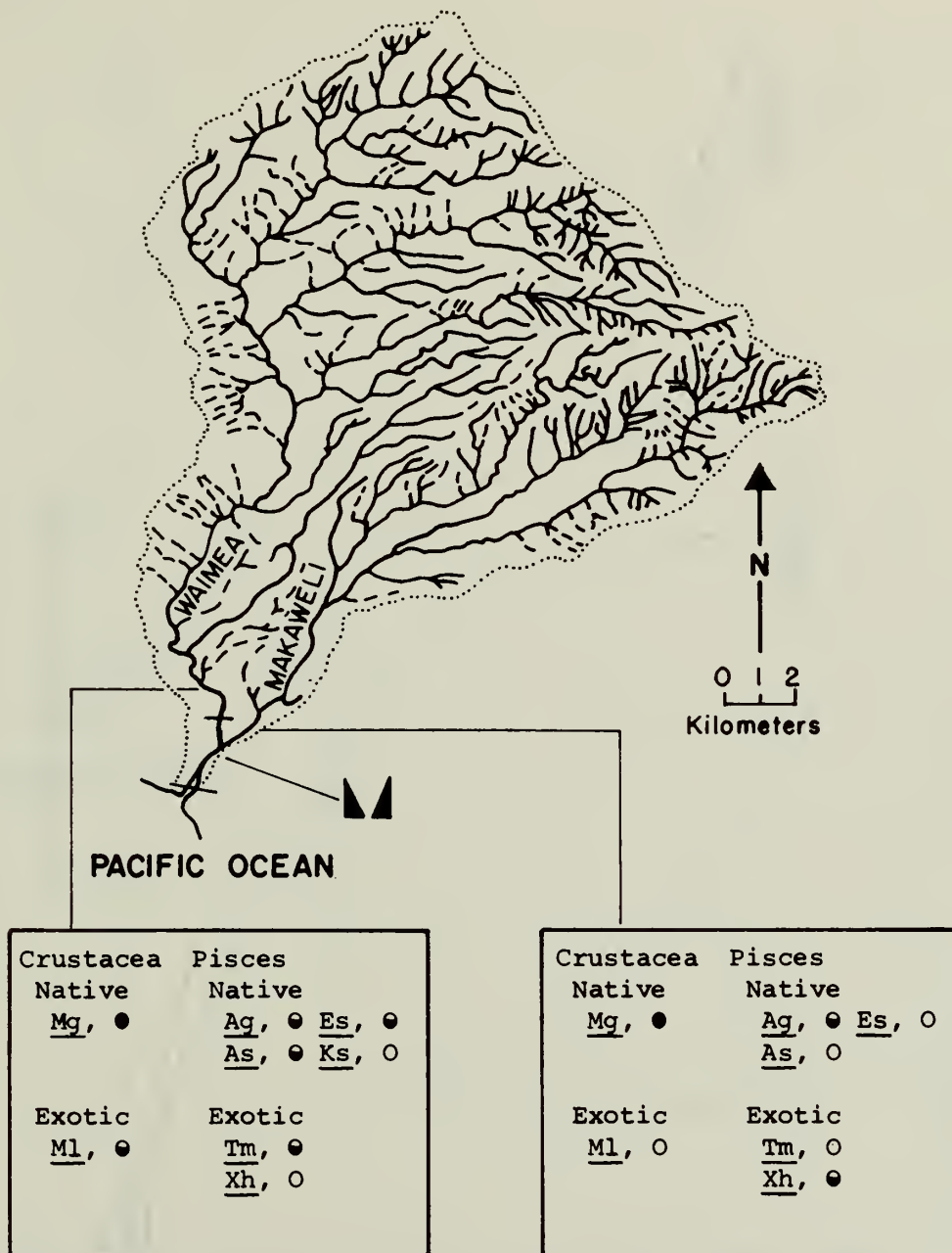


Figure B49. Waimea River, Kauai: <1% of channel length altered.

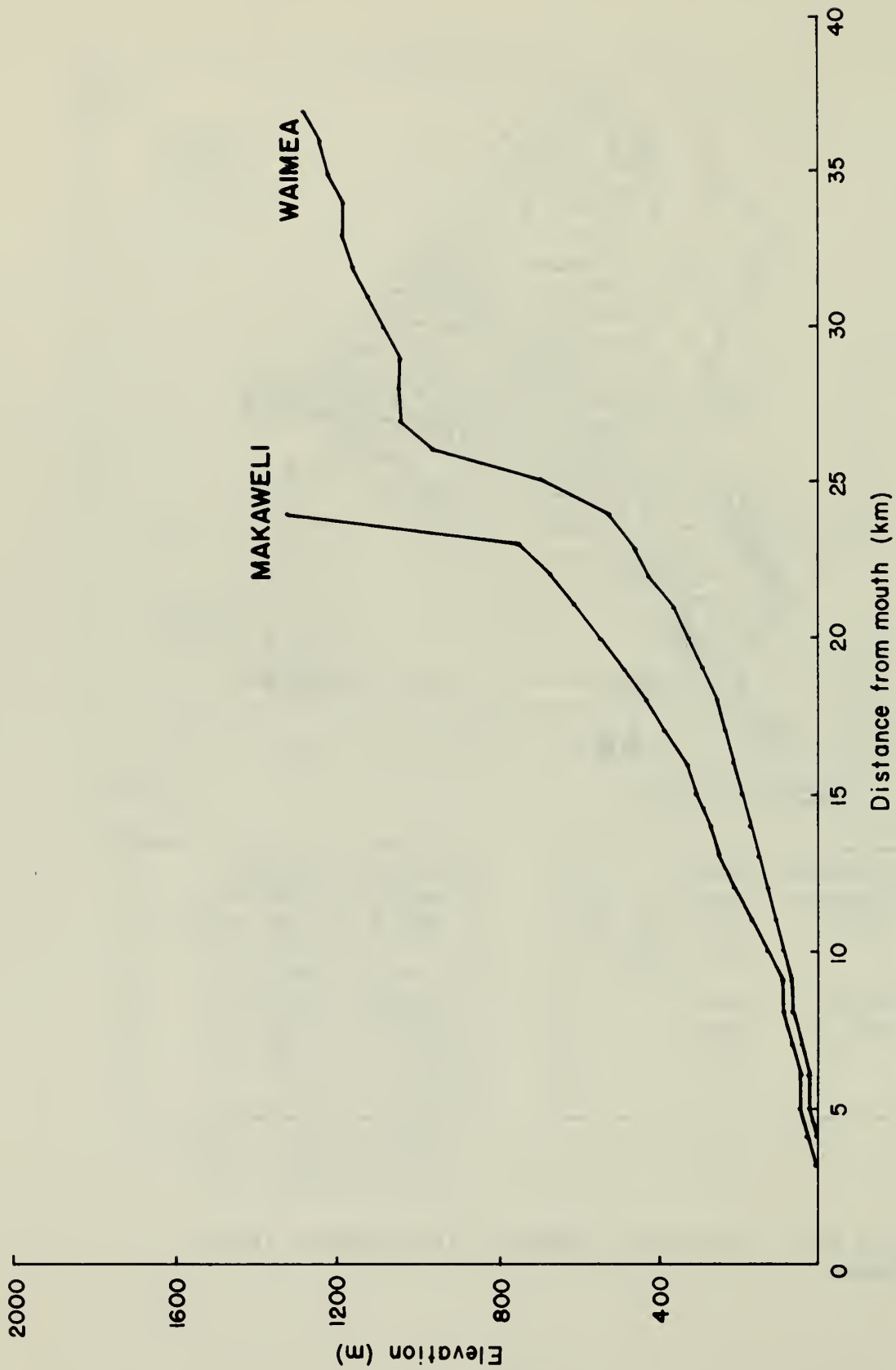


Figure B50. Profile of Waimea River, Kauai. Mainstream longitudinal gradient (m/km) = 34; Makaweli Trib. longitudinal gradient (m/km) = 55.

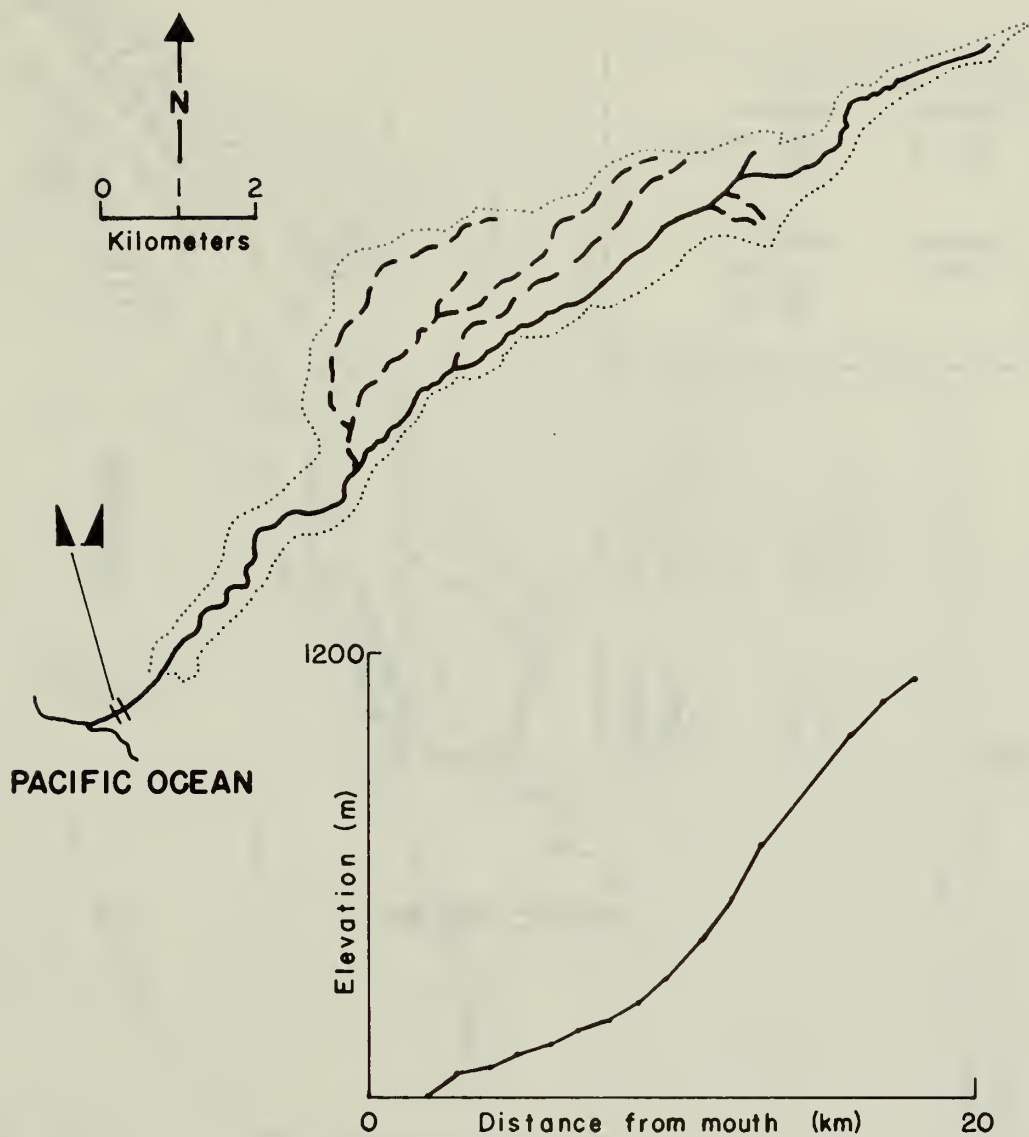


Figure B51. Waipao Stream, Kauai: <1% of channel length altered. Longitudinal gradient (m/km) = 62.

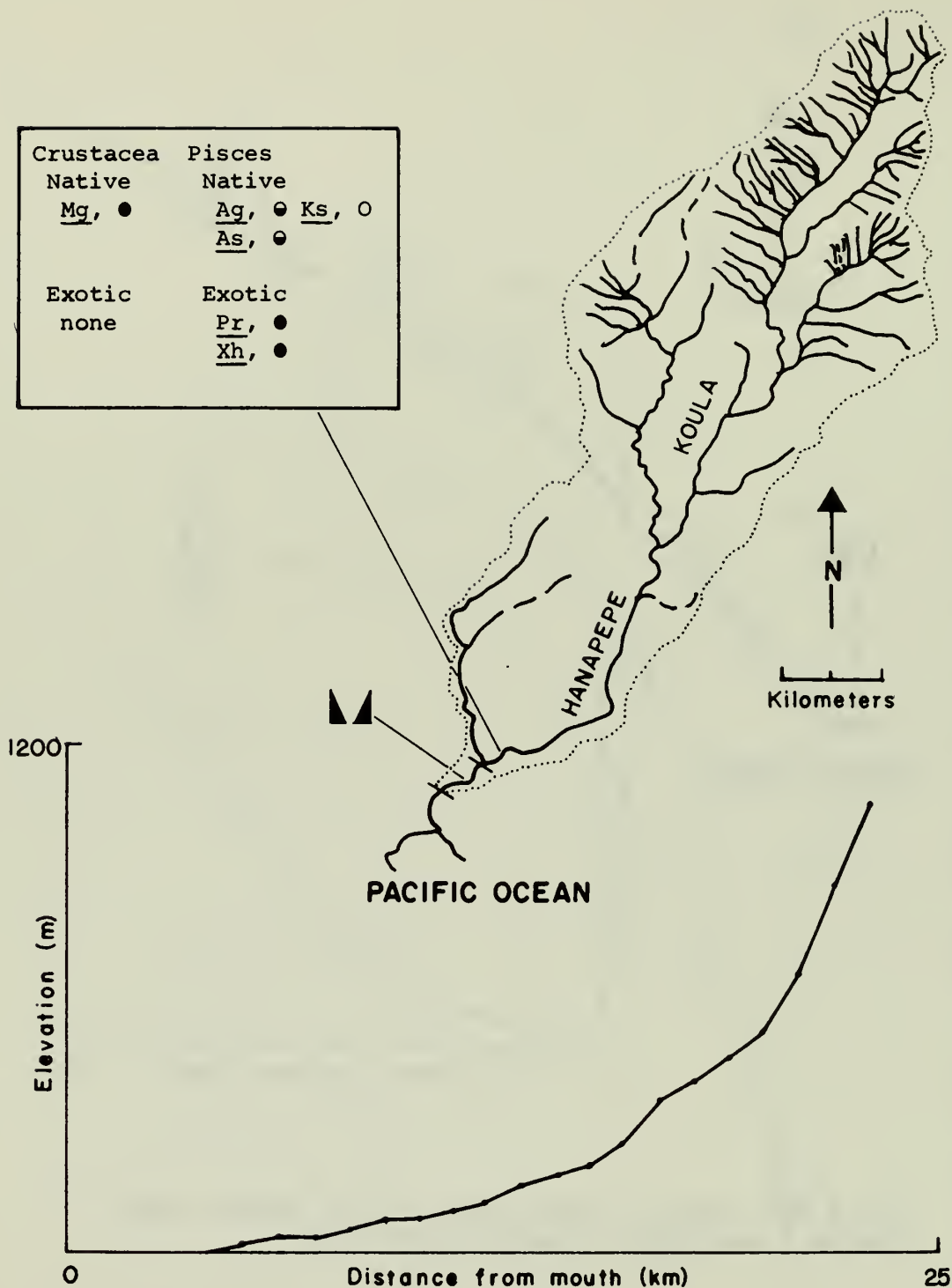


Figure B52. Hanapepe Stream, Kauai: <1% of channel length altered. Longitudinal gradient (m/km) = 46.

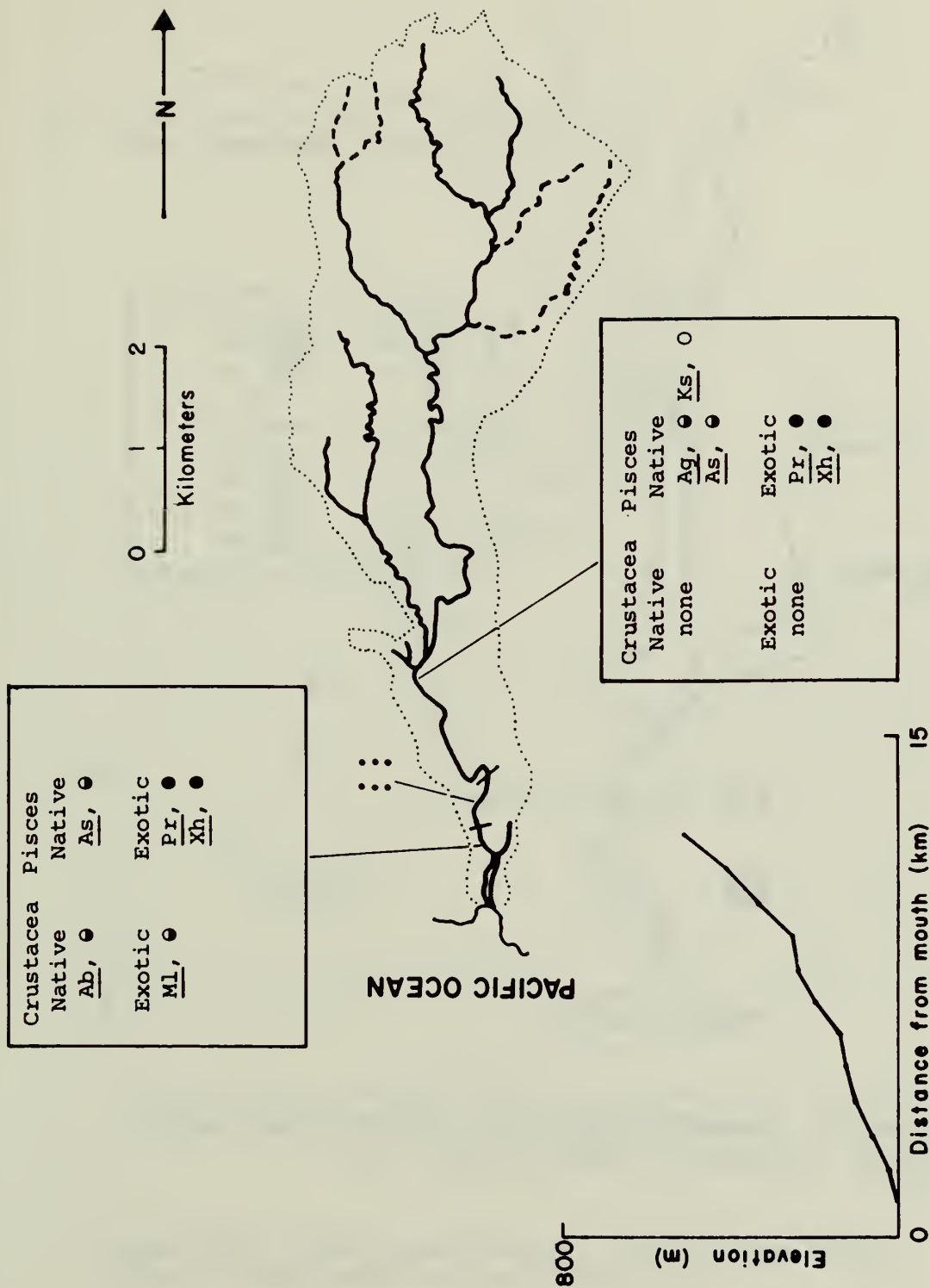


Figure B53. Lawai Stream, Kauai: 2% of channel length altered. Longitudinal gradient (m/km) = 44.

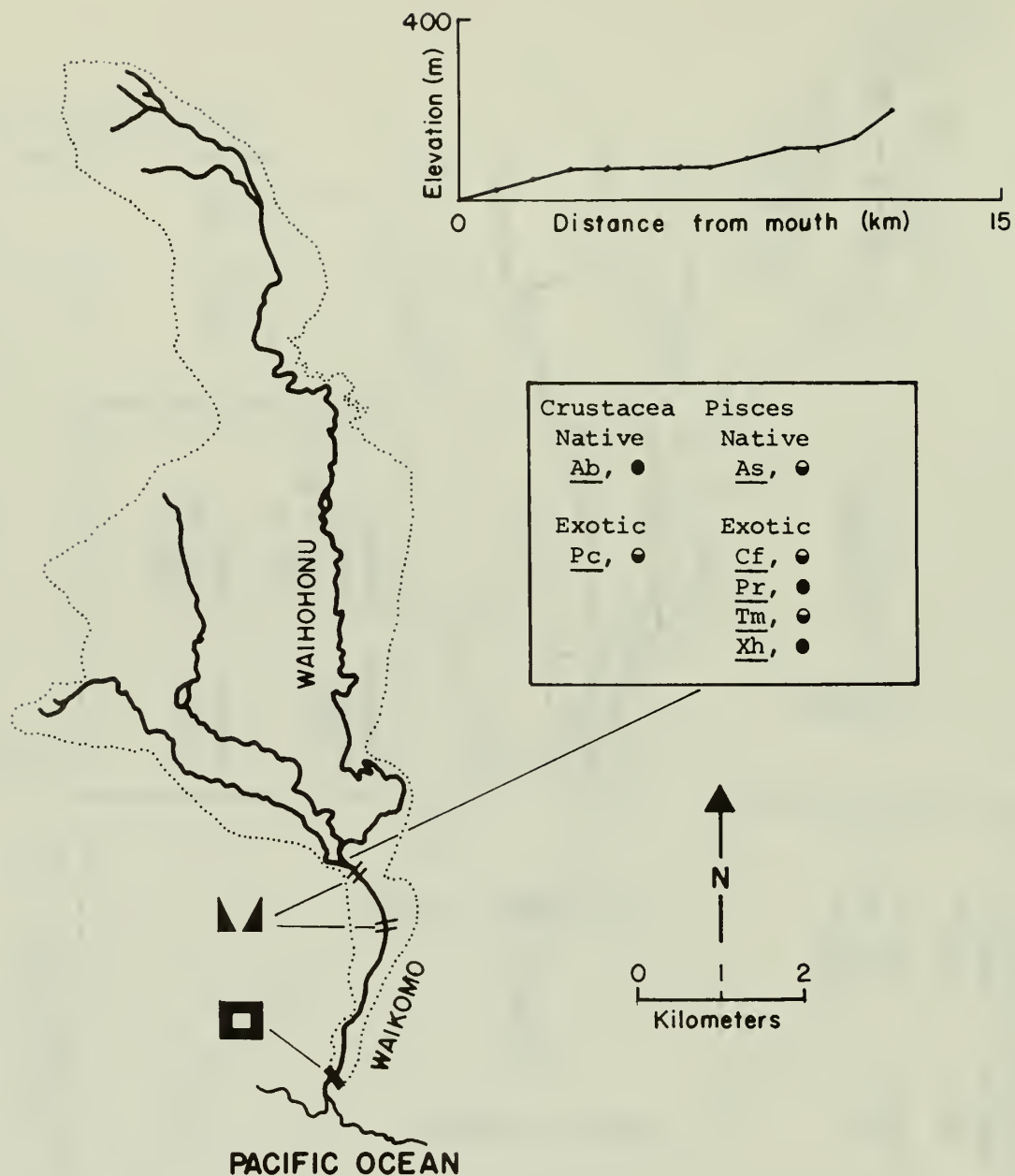


Figure B54. Waikomo Stream, Kauai: <1% of channel length altered. Longitudinal gradient (m/km) = 15.

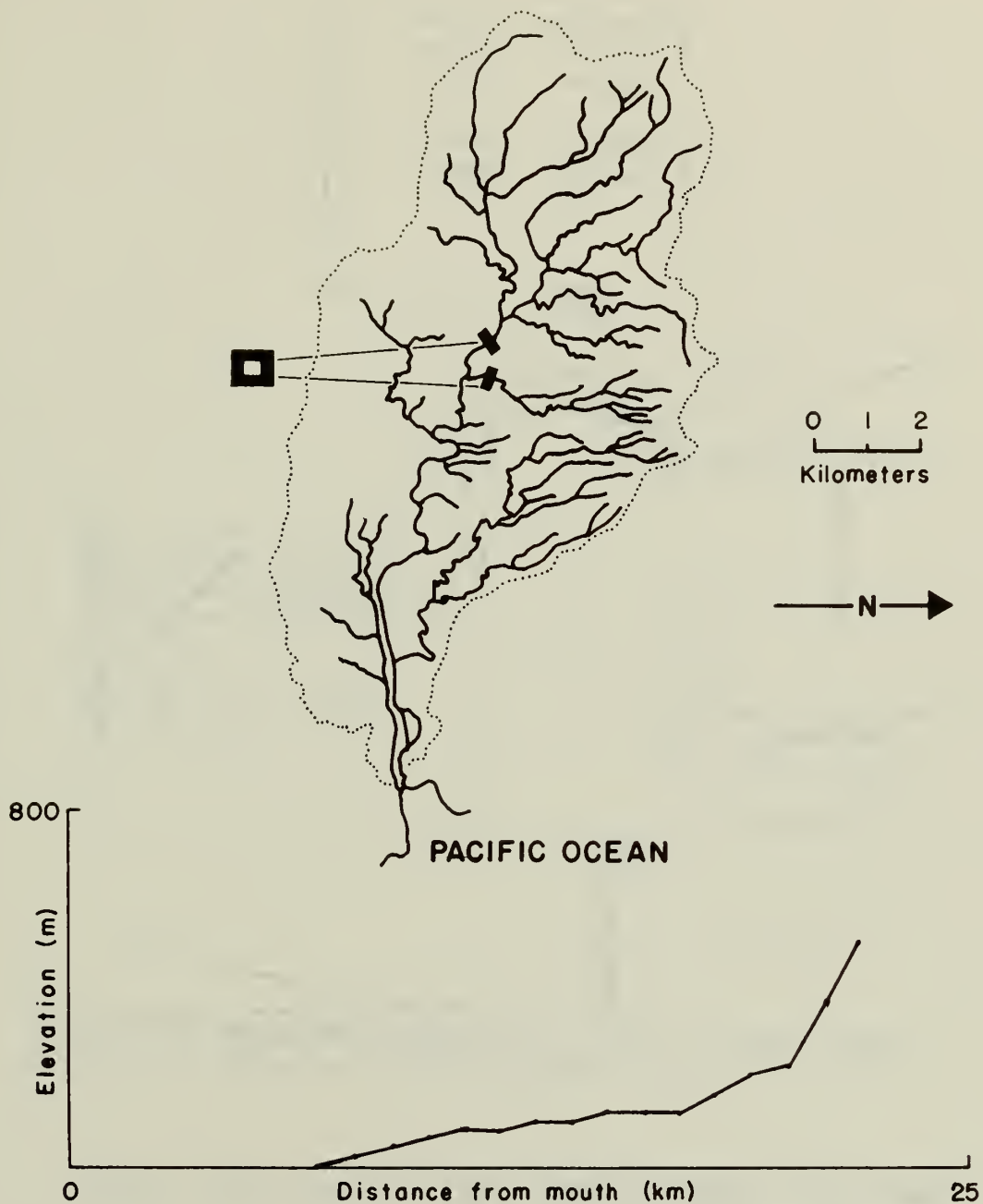


Figure B55. Huleia Stream, Kauai: <1% of channel length altered. Longitudinal gradient (m/km) = 23.

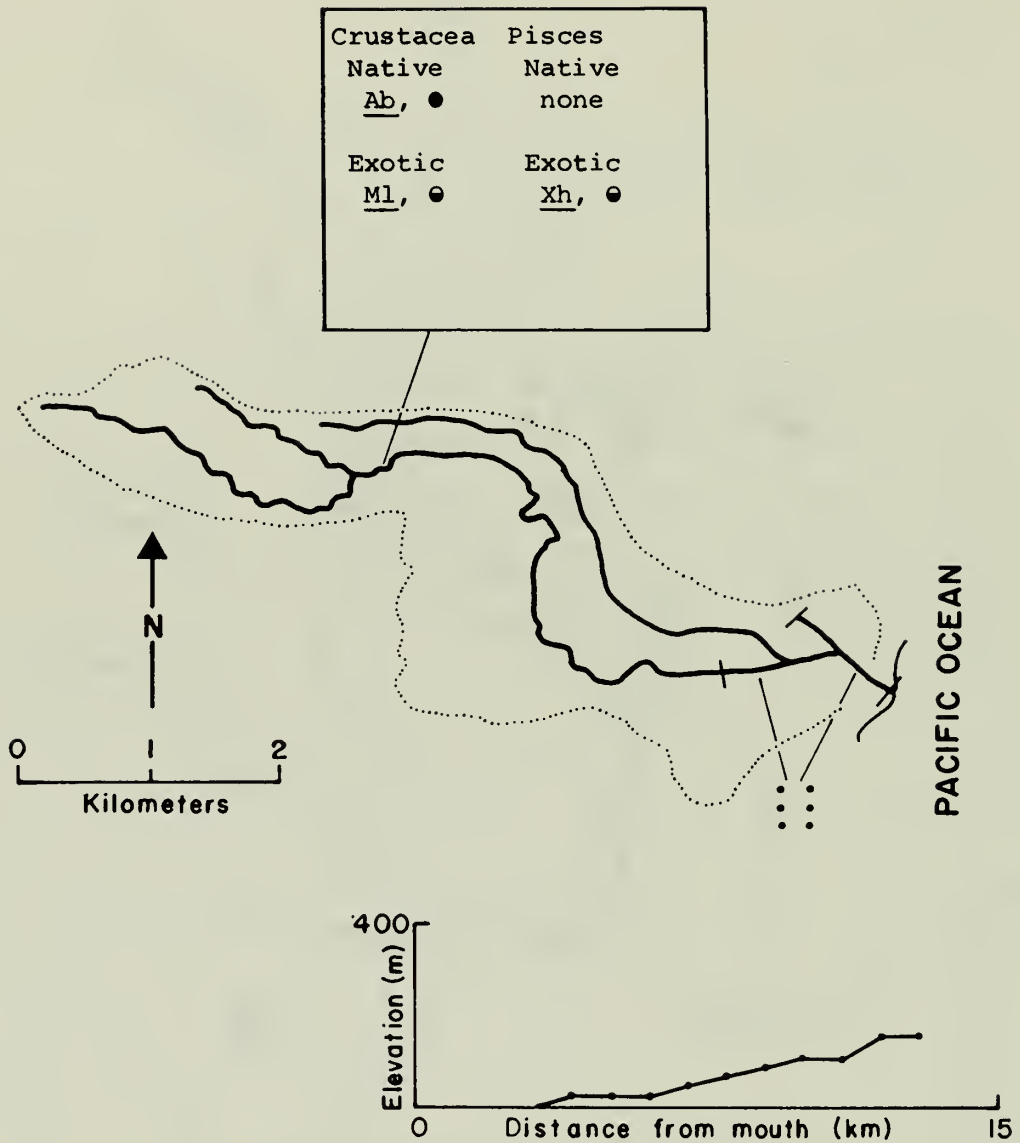


Figure B56. Konohiki Stream, Kauai: 13% of channel length altered. Longitudinal gradient (m/km) = 12.

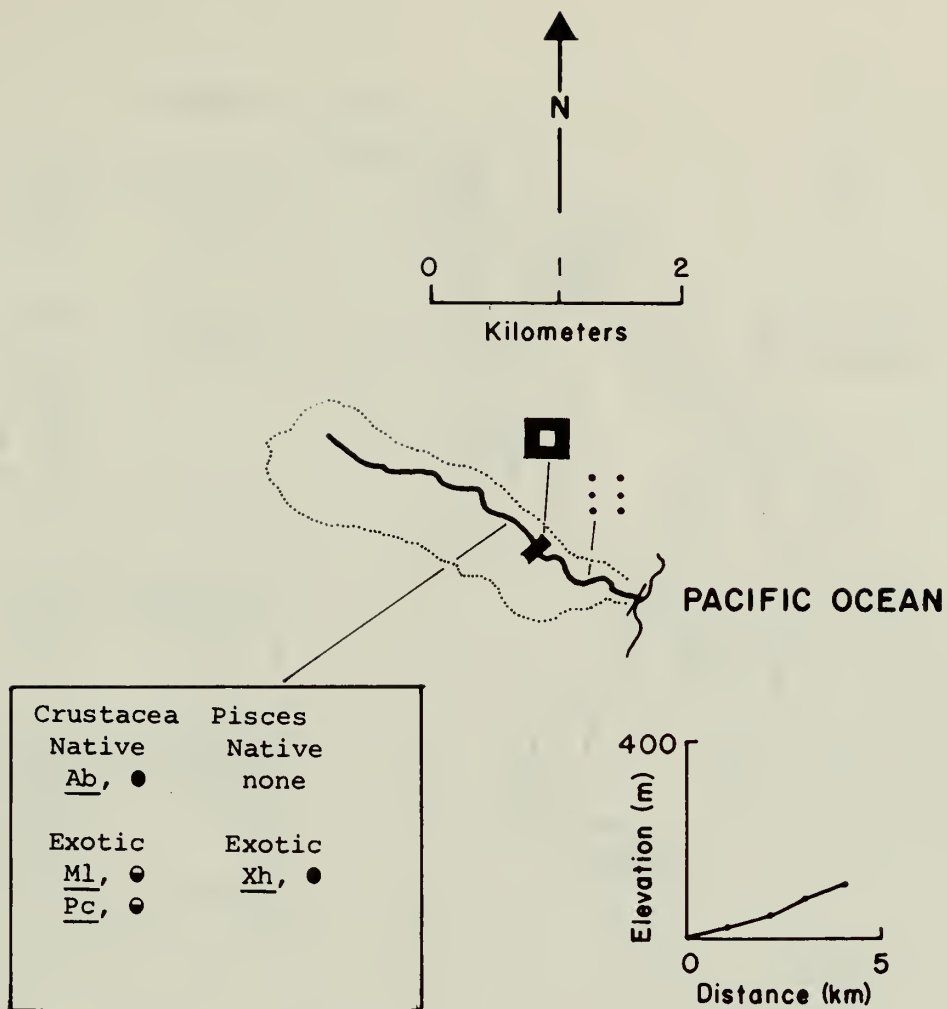


Figure B57. Kumukumu Stream, Kauai: 20% of channel length altered. Longitudinal gradient (m/km) = 27.

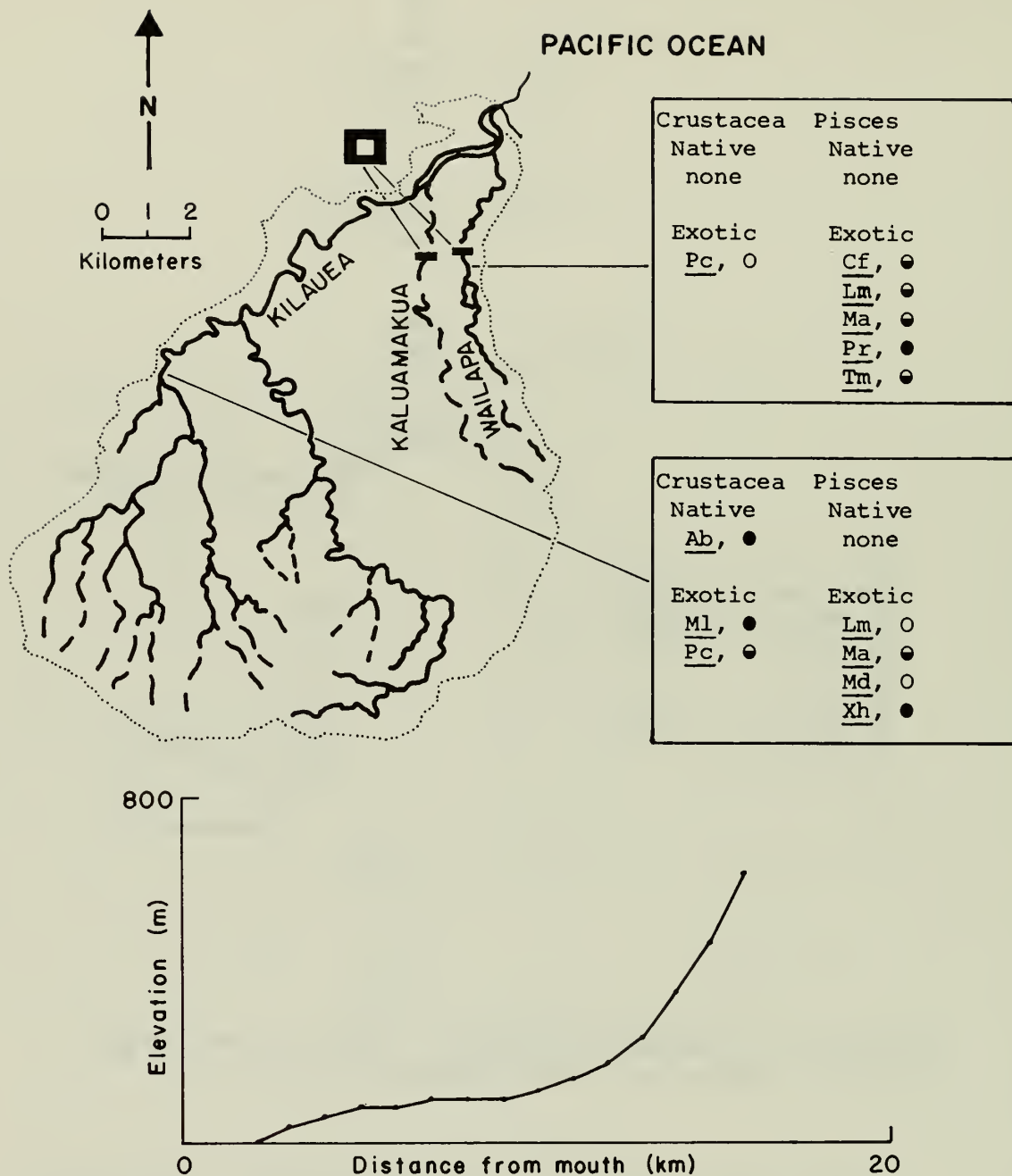


Figure B58. Kilauea Stream, Kauai: <1% of channel length altered. Longitudinal gradient (m/km) = 39.

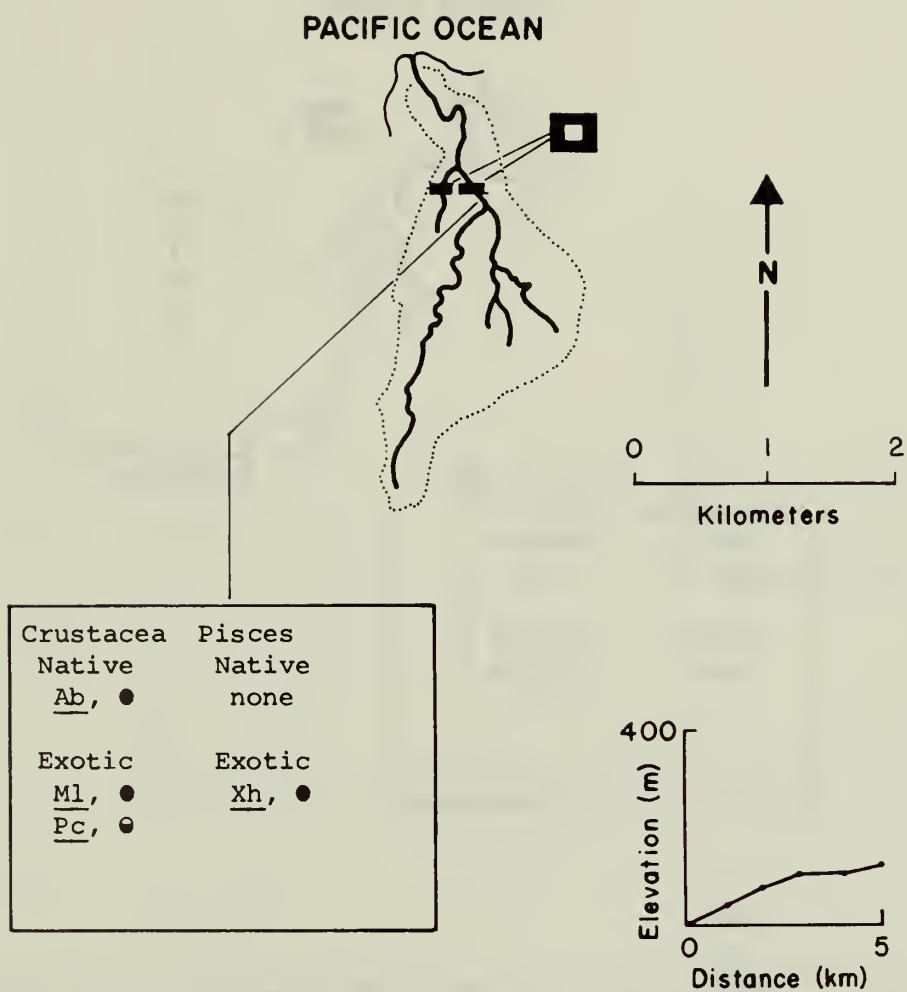


Figure B59. Puukumu Stream, Kauai: <1% of channel length altered. Longitudinal gradient (m/km) = 24.

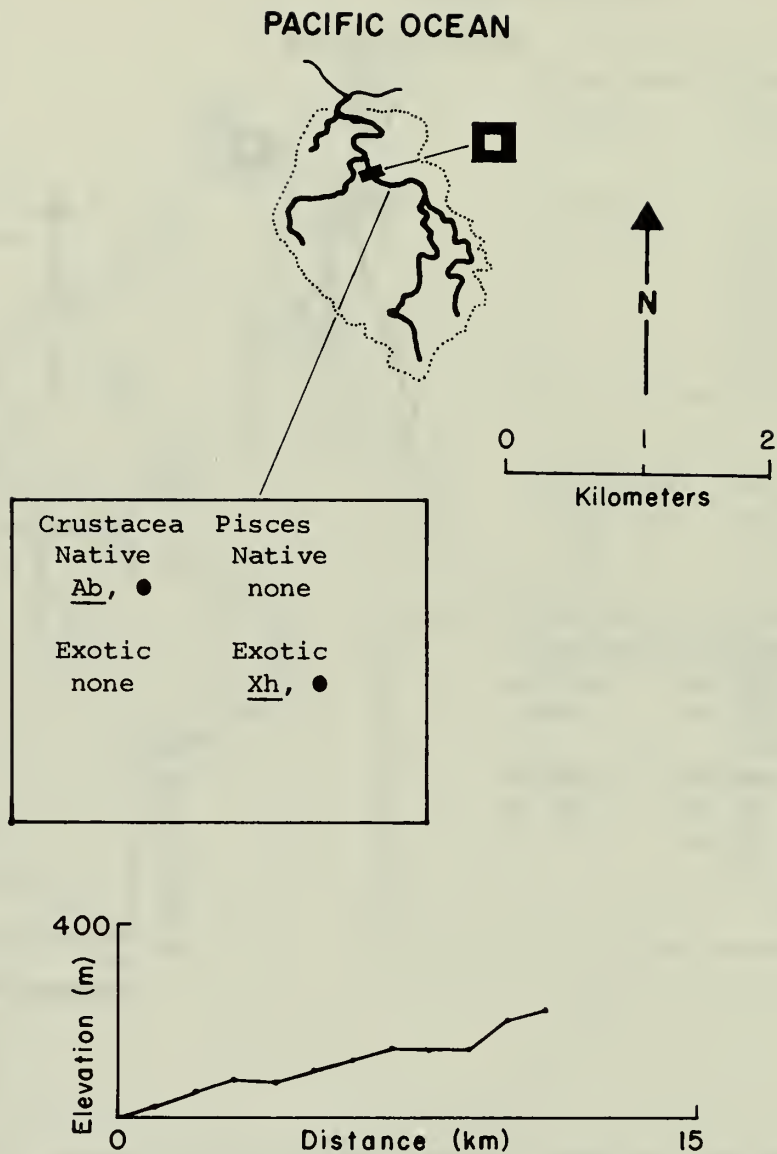


Figure B60. Anini Stream, Kauai: <1% of channel length altered. Longitudinal gradient (m/km) = 21.

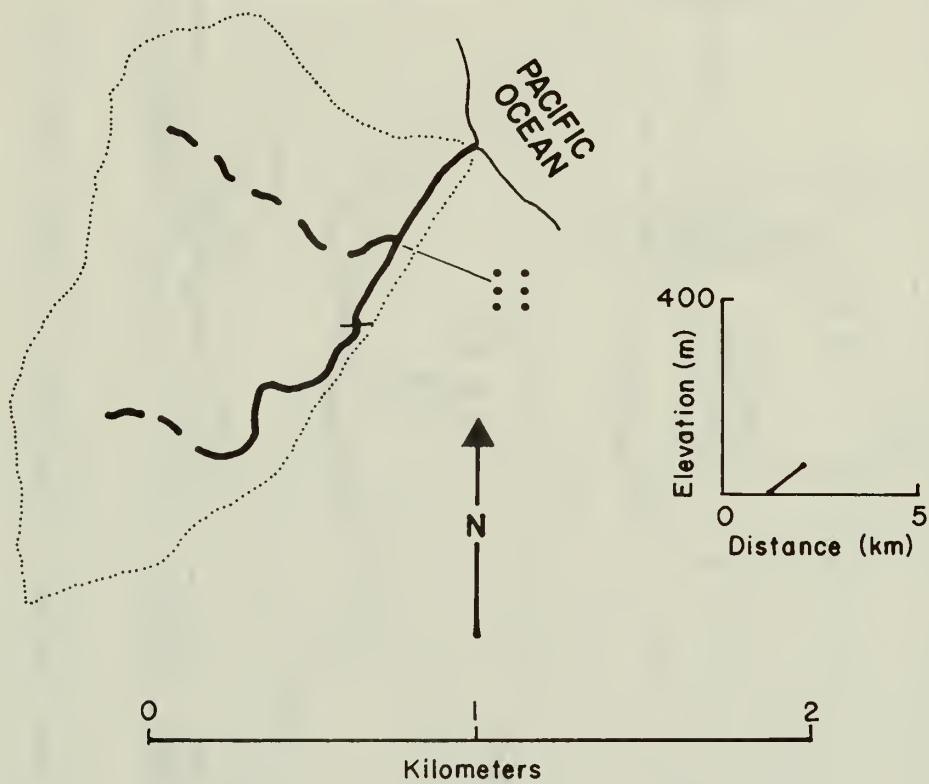


Figure B61. Waikoko Stream, Kauai: 30% of channel length altered. Longitudinal gradient (m/km) = 29.

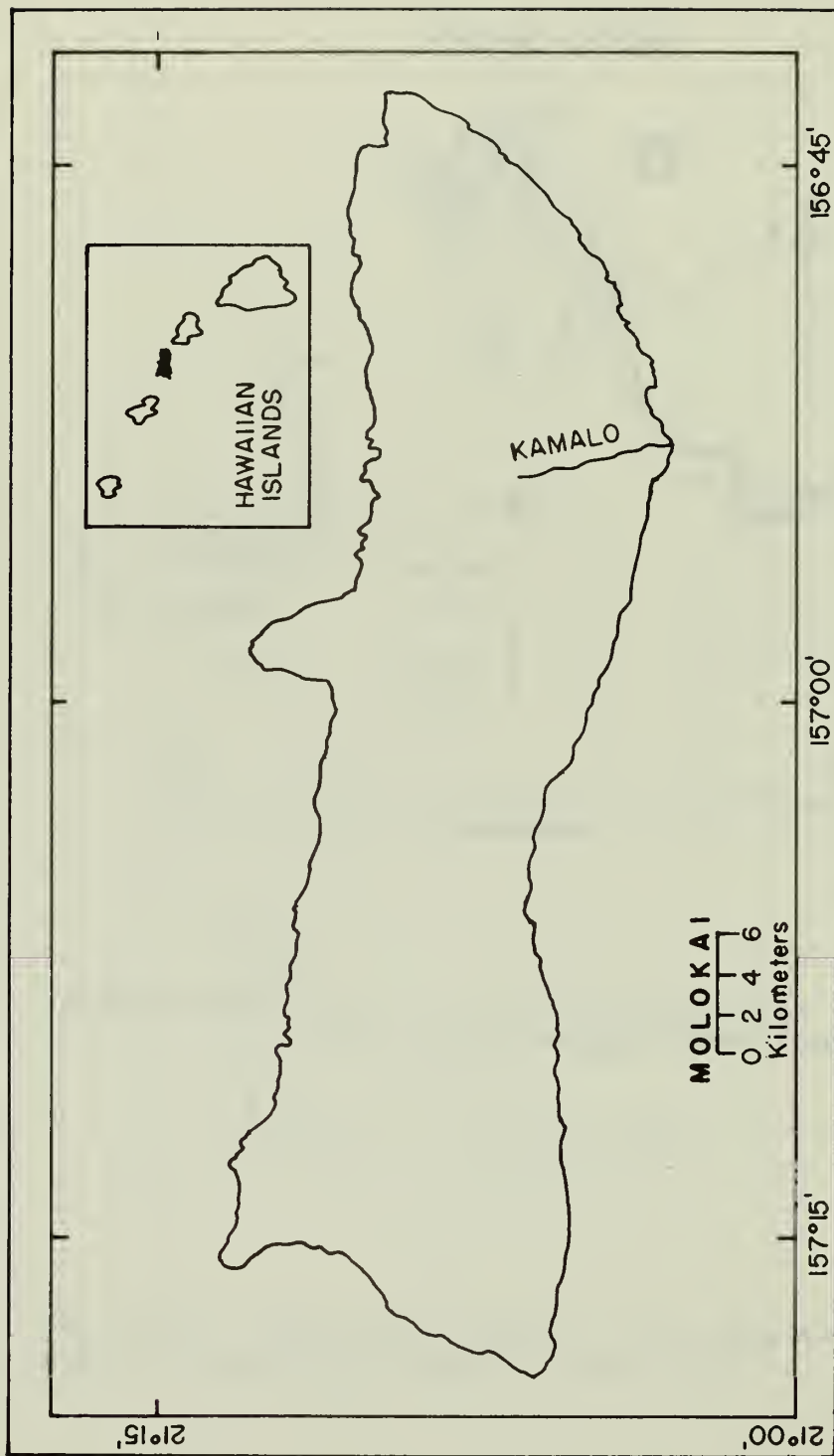


Figure B62. Locator map for Kamalo Stream, the only stream with an altered channel on Molokai.

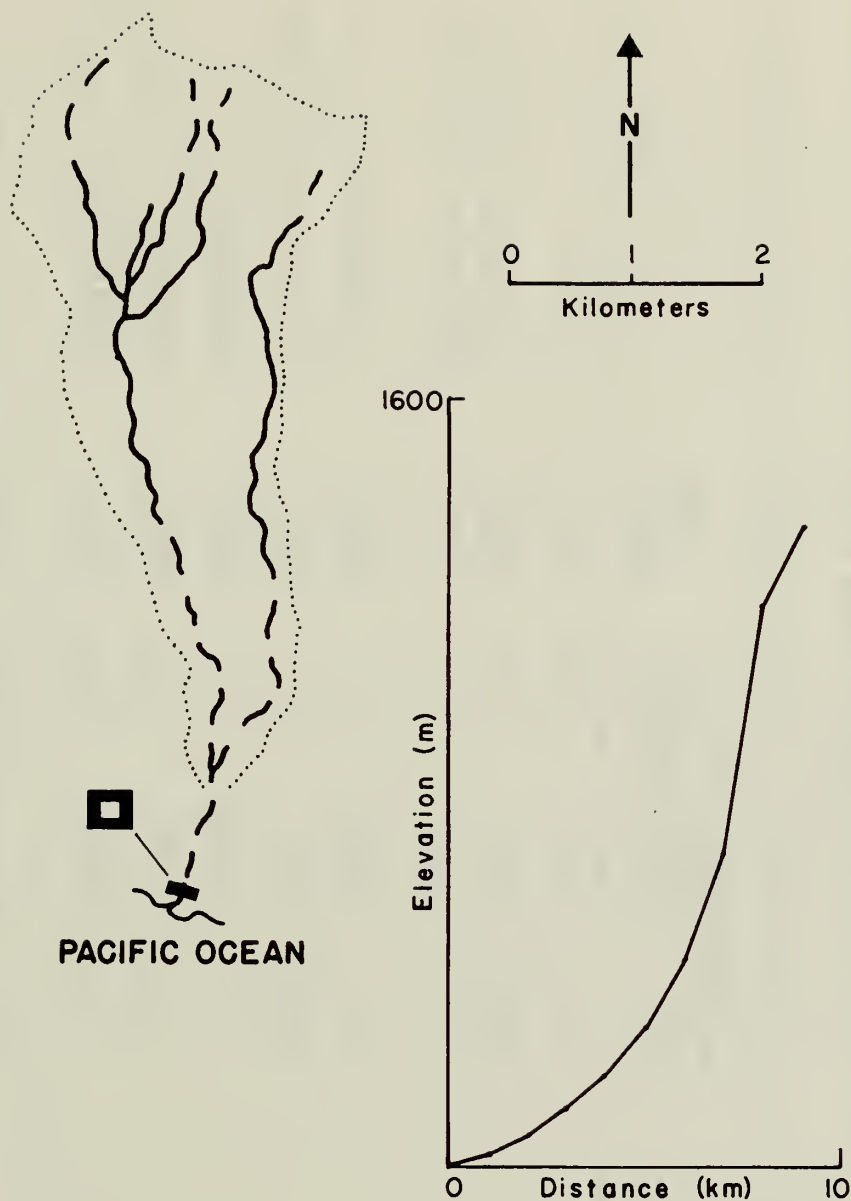


Figure B63. Kamalo Stream, Molokai: <1% of channel length altered. Longitudinal gradient (m/km) = 146.

Appendix C. Discharges of Altered Streams for which Discharge Data are Available (USGS 1977).
 See Figures C1-C4 for Gaging Station Locations. Legend: D = Diversion(s) Present
 above Gaging Station; E = Estimated; -- = No Data. Dates Indicated under
 Comments Column are Dates for Maximum Flow; Elevations
 when Indicated Refer to Gage Elevations

Island Stream	Discharge (m ³ /s)			USGS Gage No.	Comments
	Annual Mean	Instantaneous Maximum	Instantaneous Minimum		
Hawaii					
Wailoa River	0.337	16.0	0	7000	Waiakea Trib. 46-yr av., 589 m elev.
Maui					
Honokowai	--	10.818	--	6302	03/04/76, D
Kahoma	0.106	70.5	0	6385	13-yr av., D, 27 m elev.
Kauaula	--	0.283E	0	6433	03/04/76, D
Waikapu	--	8.581	--	6505	03/04/76, D
Iao	--	67.685	--	6070	03/04/76, D
Oahu					
Kaupuni	--	48.994	--	2118	02/07/76
Maliili	--	37.949	--	2122	02/07/76

Continued

Appendix C (Continued)

Island Stream	Discharge (m ³ /s)			USGS Gage No.	Comments
	Annual Mean	Instantaneous Maximum	Instantaneous Minimum		
Waikele	1.110	385.0	0.001	2130	24-yr av., D, 0.418 m elev.
Waiawa	0.935	663.0	0.048	2160	24-yr av., D, 0.552 m elev.
Waimalu	--	43.046	--	2230	11/26/75
Kalaauo	0.083	73.1	0	2245	19-yr av.
Halawa	0.143	188.0	0	2260	North Halawa 26-yr av., 98 m elev.
Moanalua	0.90	130.0	0	2280	50-yr av., 103 m elev.
Kalihi	0.329	201.0	0.005	2293	14-yr av., 21 m elev.
Nuuanu	0.203	198.0	0.003	2320	60-yr av., D, 193 m elev.
Manoa	--	77.880	--	2471	11/26/75, D, 2.2 m elev.
(Waihi)	0.103	92.0	0.002	2385	01/16/21, 58-yr av., 89 m elev.
(Waiakeakua)	0.144	87.5	0.017	2405	01/16/21, 58-yr av., D, 90 m elev.
(Palolo)	0.160	121.0	0.001	2470	12/18/67, 24-yr av., D, 29 m elev.

Continued

Appendix C (Continued)

Island Stream	Discharge (m ³ /s)			USGS Gage No.	Comments
	Annual Mean	Instantaneous Maximum	Minimum		
Wailupe	--	10.478E	--	2475	11/26/75
Kuliouou	--	6.117	--	2479	11/26/75
Waimanalo	--	21.240	--	2490	11/26/75
Maunawili	--	33.984	--	2605	11/27/75
Kaneohe	0.442	340.0	0.096	2739	14-yr av., 12 m elev.
Keaahala	--	11.910E	--	2744.99	11/25/75
Heeia	--	33.701	--	2795	11/25/75
Kahaluu	0.055	7.90	0.031	2840	South Fork Waihee Trib., 14-yr av., 188 m elev.
Malaekahana	--	8.496E	--	3105.01	11/25/75
Oio	--	5.947E	--	3110	02/07/76
Kauai					
Waimea (Waimea Mainstr.)	3.795	1,050	ca. 0 Due to upstream diversions	310	35-yr av., D, 6 m elev.

Continued

Appendix C (Concluded)

Island Stream	Discharge (m ³ /s)			Comments
	Annual Mean	Instantaneous Maximum	Instantaneous Minimum	
(Makaweli Trib.)	2.552	736	0.089	33-yr av., D, 6 m elev.
Hanapepe	2.481	1,100	0.14	52-yr av., D, 68 m elev.
Lawai	--	11.328E	--	04/03/77
Huleia	--	39.984E	--	03/19/77
Konohiki	--	1.274	--	11/26/77
Kilauea	0.320	58.6	0.051	Halaulani Trib. 18-yr av., 119 m elev.
Puukumu	--	2.917	--	07/20/76

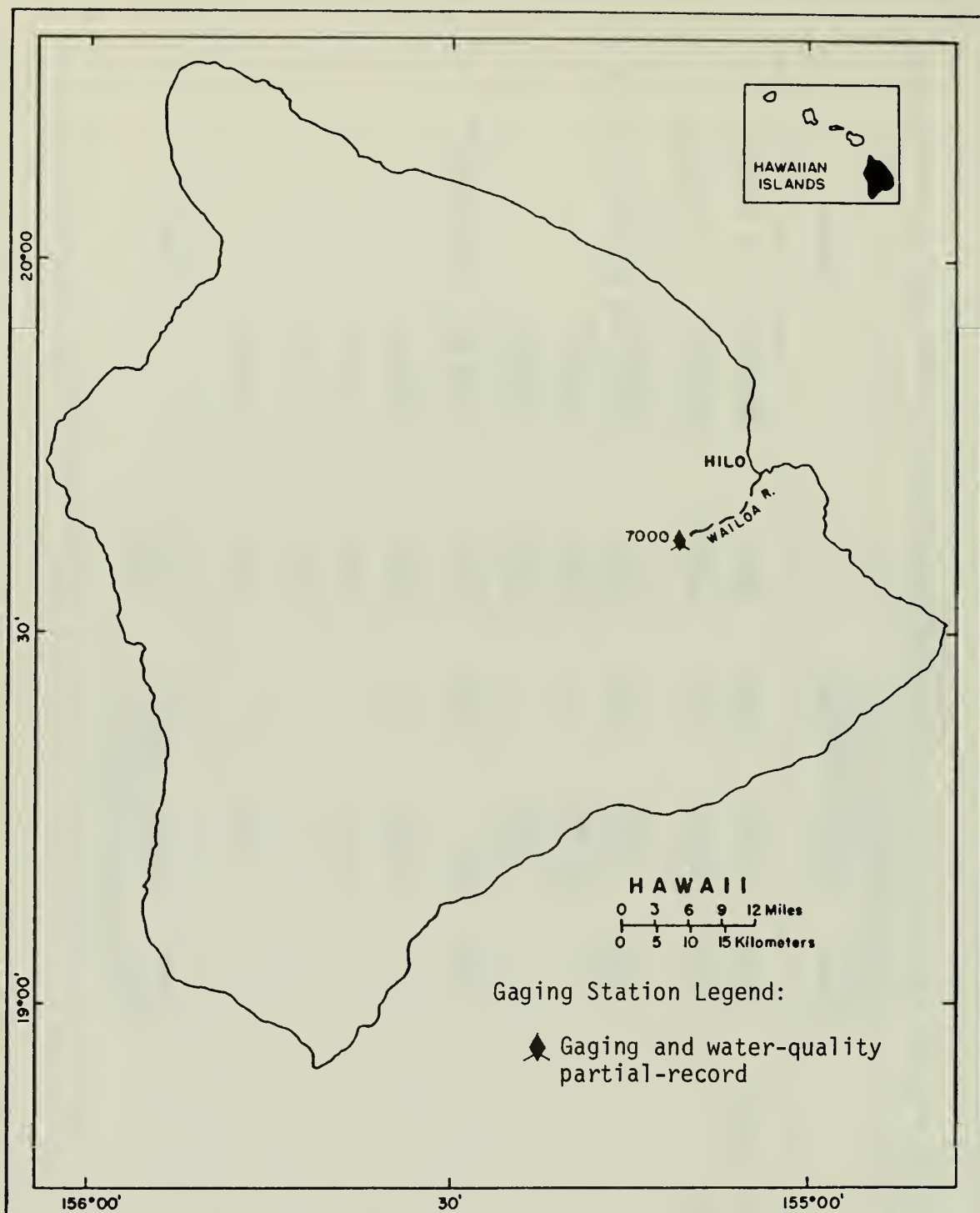


Figure C1. Location of gaging station on Wailoa River. From USGS (1977).

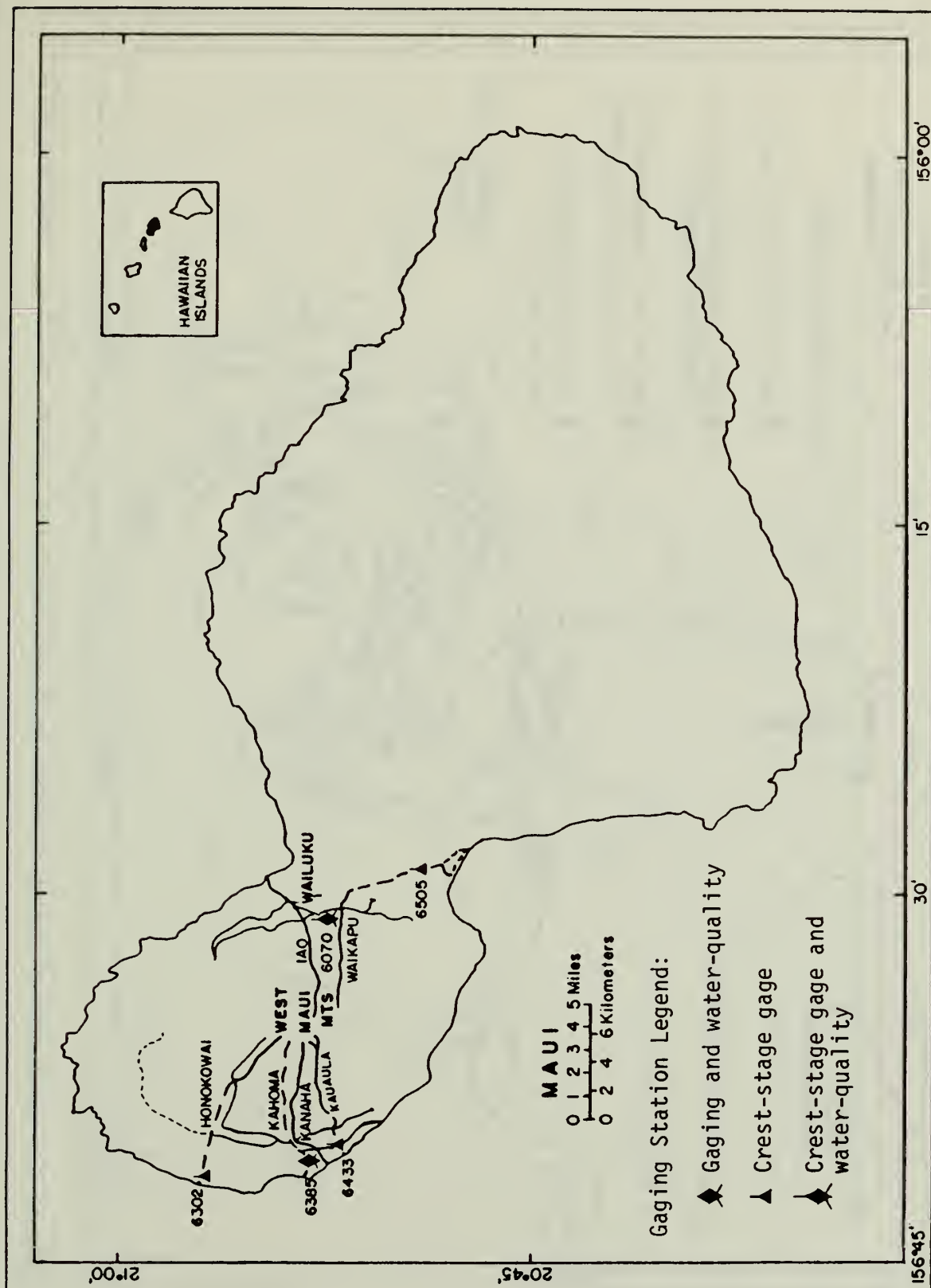
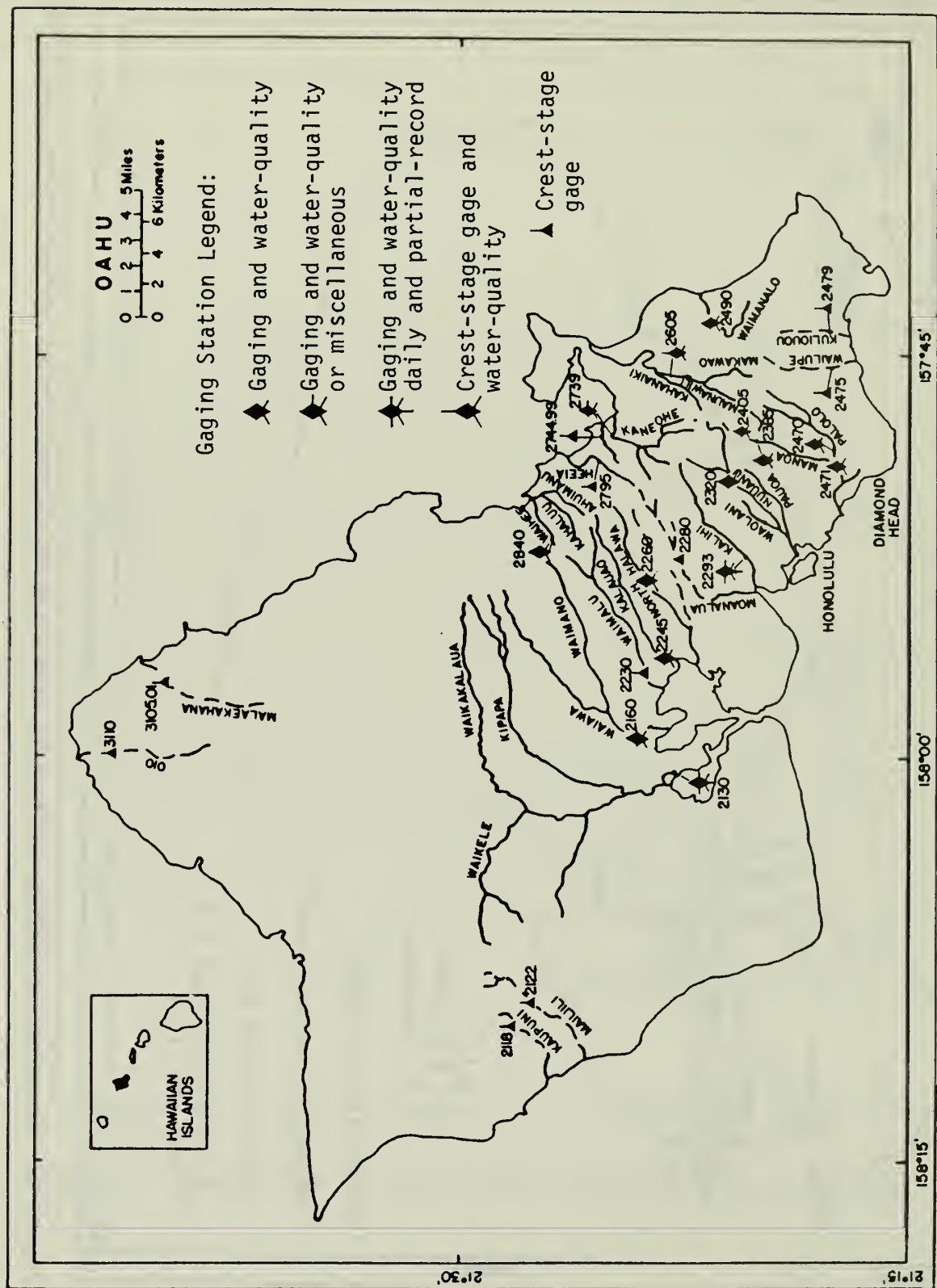
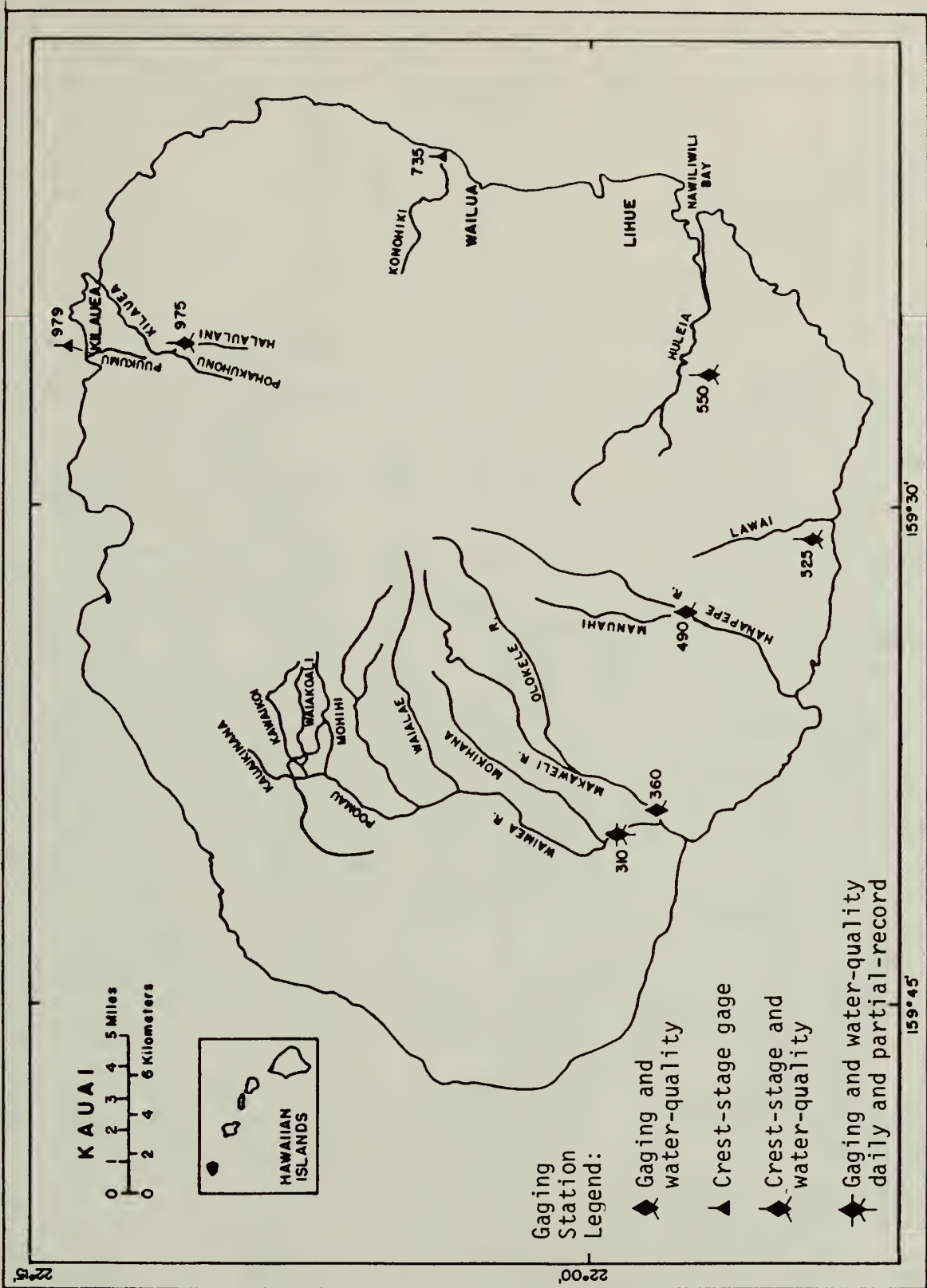


Figure C2. Locations of gaging stations in five of seven altered streams on Maui. From USGS (1977).





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7. Author(s) Timbol, A.S., Maciolek, J.A.			6.	
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12. Sponsoring Organization Name and Address National Stream Alteration Team U.S. Fish and Wildlife Service 608 E. Cherry Columbia, MO 65201			10. Project/Task/Work Unit No.	
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			13. Type of Report & Period Covered Final-Aug. 1975-Sept. 1976	
15. Supplementary Notes 171 p., 16 Fig., 16 tables, 40 Ref., 3 append.			14.	
16. Abstract (Limit: 200 words) A state wide, exhaustive inventory of perennial streams with channel modifications, including a general survey of habitat factors and macrofauna, showed that there are at least 366 perennial streams in the five largest islands of Hawaii. Fifteen percent of these streams have been altered. Six types of channel alteration have been identified: lined channel, channel realignment and riparian clearing, elevated culvert, revetment, filled-in channel, and extended culvert. A total length of 151 km of these modifications has been identified. The comparative "abundances" of these are: lined channel, 40%; realigned/cleared, 28%; revetment, 24%; filled-in channel, 5%; elevated culvert, 3%; and extended culvert, 1%. Eighty-nine percent of the total length of lined channel is located on Oahu. On the basis of other human disturbances, only 14% of Hawaiian streams may be physically pristine, and none of these physically pristine streams is on Oahu, the most populous island in the State. There are apparently no longer any biologically pristine streams, since at least one exotic species was found in all streams sampled. Only 27% are of high ecological quality (pristine-preservation use), and none of these high ecological quality streams is on Oahu. Water is exported from 53% of all perennial Hawaiian Streams. Twenty-five species of fish and decapod crustaceans were collected statewide. Only eight of the species are native to the State. Both in numbers and biomass, native species are dominant in most unaltered streams whereas exotic species are dominant in altered streams.				
17. Document Analysis a. Descriptors Streams, Profile, Attitude, Aquatic Animals, Biomass, Channeling, Channel improvement, Distribution, Diversion, Ecology, Surveys, Crustaceans, Habitats, Hawaii, Perennial streams Geomorphology, Retaining walls, Riparian land, Riparian plants, Land clearing, Consumptive use, Degradation (stream), Water quality, Water temperature.				
b. Identifiers/Open-Ended Terms Awaous stamineus, Pristine streams, Channelization, Channel realignment, Concrete-lined channels, Dissolved inorganic ions, Abundance, Elevated culverts, Endemic species, Exotic species, Extended culverts, Filled-in channels, Decapods, Goby, Indicator species, Indigenous species, Interrupted streams, Kauai Island, Lentipes concolor, Maui Island, Molokai Island, Oahu Island, Poeciliids, Inventories.				
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